This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

K.F. WENDT LIBRARY
UW COLLEGE OF ENGR.
215 N. RANDALL AVENUE
MADISON

INTERNATIONAL
LIBRARY OF TECHNOLOGY

A SERIES OF TEXTBOOKS FOR PERSONS ENGAGED IN THE ENGINEERING
PROFESSIONS AND TRADES OR FOR THOSE WHO DESIRE
INFORMATION CONCERNING THEM. FULLY ILLUSTRATED
AND CONTAINING NUMEROUS PRACTICAL
EXAMPLES AND THEIR SOLUTIONS

ELECTRICITY AND MAGNETISM
PRINCIPLES OF TELEPHONY
SUBSCRIBERS' STATION EQUIPMENT
CENTRAL-OFFICE EQUIPMENT
OUTSIDE PLANT
MAINTENANCE AND ORGANIZATION

SCRANTON:
INTERNATIONAL TEXTBOOK COMPANY
143

Electricity and Magnetism: Copyright, 1916, by INTERNATIONAL TEXTBOOK COMPANY.

Principles of Telephony: Copyright, 1916, by INTERNATIONAL TEXTBOOK COMPANY.

Subscribers' Station Equipment: Copyright, 1916, by INTERNATIONAL TEXTBOOK COMPANY.

Central-Office Equipment: Copyright, 1916, by INTERNATIONAL TEXTBOOK COMPANY.

Outside Plant: Copyright, 1916, by INTERNATIONAL TEXTBOOK COMPANY.

Maintenance and Organization: Copyright, 1916, by INTERNATIONAL TEXTBOOK COMPANY.

Copyright in Great Britain

All rights reserved

PRESS OF
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.

143

70561

206729
OCT 25 1916
SB
.IN82
143

PREFACE

The volumes of the International Library of Technology are made up of Instruction Papers, or Sections, comprising the various courses of instruction for students of the International Correspondence Schools. The original manuscript for each Instruction Paper is prepared by a person thoroughly qualified, both technically and by experience, to write with authority on his subject. In many cases the writer is regularly employed elsewhere in practical work and writes for us during spare time. The manuscripts are then carefully edited to make them suitable for correspondence work.

The only qualification for enrolment as a student in these Schools is the ability to read English and to write intelligibly the answers to the Examination Questions. Hence, our students are of all grades of education, and our Instruction Papers are, therefore, written in the simplest possible language so as to make them readily understood by all students. If technical expressions are essential to a thorough understanding of the subject, they are clearly explained when first introduced.

The great majority of our students wish to prepare themselves for advancement in their vocations or to qualify for other and more congenial occupations. Their time for study is usually after the day's work is done and is limited to a few hours each day. Therefore, every effort is made to give them practical and accurate information in clear, concise form, and to make this information include all of the essentials but none of the non-essentials. To effect this result derivations of rules and formulas are usually omitted, but thorough and complete instructions are given regarding how, when, and under what conditions any particular rule, formula, or process should be applied. Whenever possible one or more examples, such as would be likely to arise in actual practice, together with their solutions, are given for illustration.

As the best way to make a statement, explanation, or description clear is to give a picture or a diagram in connection with it, illustrations are very freely used. These illustrations are especially made by our own Illustrating Department in order to adapt them fully to the requirements of the text. Projection drawings, sectional drawings, outline drawings, perspective drawings, partly shaded or full shaded, are employed, according to which will best produce the desired result. Half-tone engravings are used only in those cases where the general effect is desired rather than the actual details.

In the table of contents that immediately follows are given the titles of the Sections included in this volume, and under each title is listed the main topics discussed. At the end of the volume will be found a complete index, so that quick reference can be made to any subject treated.

INTERNATIONAL TEXTBOOK COMPANY

CONTENTS

ELECTRICITY AND MAGNETISM

	Section	Page
Electricity	10	1
Primary Batteries	10	5
General Classes of Electric Currents	10	7
Electrical Units and Relations	10	8
Practical Units	10	8
Ohm's Law	10	8
Conductors and Circuits	10	10
Electric Circuits	10	11
Static Electricity	10	12
Electric Charges	10	12
Condensers	10	13
Magnets and Magnetism	10	16
General Properties of Magnets	10	16
Relations Between Electricity and Magnetism	10	22
Magnetic Effect of Electric Current	10	22
Electromagnetic Solenoid	10	24
Electrical Measuring Instruments	10	25
Electromagnets	10	26
Induced Electromotive Forces	10	31
Electromagnetic Induction	10	31
Mutual Induction	10	33
Induction Coils	10	34
Self-Induction	10	36
Impedance Coils	10	38

PRINCIPLES OF TELEPHONY

	Section	Page
Acoustics	11	1
Cause and Nature of Sound	11	1

PRINCIPLES OF TELEPHONY—*Continued* *Section* *Page*

Reproduction of Sound 11 5
Receivers and Transmitters 11 7
Telephone Receiver 11 8
Telephone Transmitters 11 9
Electric Signaling 11 15
Magneto Generators 11 15
Polarized Bells 11 18
Connections for Signaling 11 19
Series Magnetos 11 20
Bridging Magnetos 11 20
Hook Switch 11 22
Inductive Disturbances 11 24
The Telephone Exchange 11 26
Definition of Terms 11 26
Magneto Exchanges 11 27
Common-Battery Exchanges 11 31
Signaling the Operator 11 31
Signaling the Subscriber 11 34
Telephone Protection 11 36
Electric Hazards 11 36
Heating Effect of Electric Current 11 36
Chemical Effect of Electric Current 11 39

SUBSCRIBERS' STATION EQUIPMENT

Single-Station Equipment 12 1
Classification 12 1
Component Parts of Telephone Instruments 12 2
Transmitters 12 2
Receivers 12 5
Induction Coils 12 6
Ringers 12 7
Magneto Generators 12 9
Hook Switch 12 11
Local Batteries 12 12
Condensers 12 12
Types of Subscribers' Instruments 12 13
Magneto, or Local-Battery, Instruments . . 12 13

SUBSCRIBERS' STATION EQUIPMENT—*Continued* *Section* *Page*
Common-Battery Instruments 12 16
Party-Line Telephones 12 20
Magneto Party Lines 12 20
Common-Battery Party Lines 12 21
Subscribers' Multi-Station Systems 12 24
Extension Telephones 12 24
Typical Plans for Extension Telephones . . 12 25
Private Branch Exchanges 12 30
Cordless Switchboard 12 30
Auxiliary Devices for Cord-Type Branch Exchanges 12 35
Jacks and Plugs 12 35
Cords 12 37
Line Signals 12 38
Relays 12 41
Magneto Private Branch Exchange 12 44
Common-Battery Private Branch Exchanges 12 44
New York Type No. 1 Board 12 45
Type No. 4 P. B. X. Board 13 1
Circuits 13 2
Line Circuits 13 2
Trunk Circuits 13 4
Cord Circuits 13 5
Operation 13 5
Call From Central Office to Extension Station 13 5
Calls From Extension Stations 13 9
Charging Trunks 13 10
Pilot Signals 13 10
Multiple Boards 13 11
Subscribers' Station Protection 13 11
Necessity for Protection 13 11
Means of Protection 13 12
Installing Telephone Apparatus 13 15
Interior Wiring 13 15
Wire Gauges 13 15
Copper Wire 13 18
Installation of Conductors 13 19

SUBSCRIBERS' STATION EQUIPMENT—*Continued* *Section* *Page*
General Method of Running Wires 13 19
Fastening Inside Wires 13 20
Splicing Inside Wires 13 22
Wiring Large Buildings 13 24
Installation of Telephones 13 33
Instructions to Installers 13 35
Plant Records 13 35
General Deportment 13 36
Checking Conductor Assignments 13 37
Miscellaneous Points 13 37
Maintenance of Subscribers' Equipment . . 13 39
General Inspection and Tests 13 39
Subscribers' Station Troubles 13 45

CENTRAL-OFFICE EQUIPMENT
General Features of a Telephone Central Office 14 1
Classification and Definitions 14 1
Magneto Switchboards 14 4
Common-Battery Switchboards 14 14
Terminal Apparatus 14 31
Central-Office Wiring 14 39
Switchboard Wire and Cable 14 39
Power Plant 14 61
Magneto Power Plant 14 61
Common-Battery Power Plants 14 63

OUTSIDE PLANT
Surface Plant 15 1
General Features of Outside Plants 15 1
Drop Wiring 15 3
Block Wiring 15 7
Pole Lines 15 9
Telephone Poles 15 9
Pole Hardware 15 12
Placing Poles 15 13
Aerial Wire 15 19
Aerial Cable Installation 15 21

OUTSIDE PLANT—*Continued* *Section* *Page*
Cable Terminals 15 21
Aerial Cable 15 25
Block Cable 15 40
House Cables 15 45
Making and Splicing Paper-Insulated Cables 15 49
Joint Use of Poles 15 54
Resuscitation After Electric Shock 15 58
Underground Plant 15 60
Subway Construction 15 60
Underground Cable 15 67
Drawing in Cable 15 67
Placing Lateral Cables 15 70
Cross-Connection Boxes 15 70
Testing and Splicing Underground Cable . . 15 71

MAINTENANCE AND ORGANIZATION

Plant Maintenance 16 1
Necessity for Inspections and Tests 16 1
Testing and Measuring Instruments 16 3
Lineman's Test Set 16 3
The Wheatstone Bridge 16 4
Voltmeters and Ammeters 16 7
Cable-Testing Sets 16 9
Wire Chief's Testing Equipment 16 10
Determination of Faults 16 16
Location of Faults 16 19
Switchboard Tests 16 22
Order of Clearing Central-Office Trouble . . 16 23
Use of Lineman's Test Set 16 24
Company Organization 16 26
Plant Department 16 26
Construction Department 16 26
Equipment Department 16 27
Record Department 16 29
Traffic Department 16 30
Commercial Department 16 31
Engineering Department 16 32

ACKNOWLEDGMENT

Acknowledgment is hereby made of indebtedness to the American Telephone and Telegraph Company and the Western Electric Company for valuable criticisms and photographs as well as for permission to use statements of principles and illustrations from copyrighted publications.

INTERNATIONAL TEXTBOOK COMPANY

ELECTRICITY AND MAGNETISM

ELECTRICITY

GENERAL CHARACTERISTICS

1. The general characteristics of electricity and the laws according to which it acts are well understood. In discussions of electricity, it is commonly assumed to act like a fluid. For example, it is said to flow through conductors, and its flow is caused by electric pressure, in the same way that the flow of water through pipes is caused by pressure. The assumption is not wholly correct, for there is no actual flow of electricity in a conductor similar to the flow of water in a pipe; but many things about electricity can be more clearly explained and more easily understood by conceiving it to act like a fluid.

Three of the most important elements that enter into ordinary calculations of electricity are *electric current*, *electromotive force*, and *electric resistance*.

2. An **electric current** is a flow of electricity, and this flow is assumed to have direction. Electric current is caused by **electromotive force,** or *electric pressure*, which may be compared to the pressure causing flow of water in a pipe. The flow of electricity, or the electric current, in a given conductor depends on the electromotive force causing it, just as the rate at which water flows through a pipe depends on the pressure forcing it through. Electromotive force is frequently abbreviated E. M. F.

3. The **electric potential** of a body has reference to its electrical condition compared with that of some other body,

COPYRIGHTED BY INTERNATIONAL TEXTBOOK COMPANY. ALL RIGHTS RESERVED

just as the *head* of a liquid is the height of its surface above some point used for comparison. If the bottoms of two tanks in which water stands at different levels, or heads, are connected by a pipe, water will flow through the pipe, owing to the pressure, or *motive force*, caused by the *difference of heads* in the two tanks, and this flow will continue until the heads are the same. Likewise, if two electrical bodies, charged at different potentials, are connected by a conductor, electricity will flow through the conductor from the higher to the lower potential, and this flow, or current, will continue as long as a *difference of potential* exists.

In reality, an electromotive force causes a difference of potential and electric current results therefrom, but in practice the two expressions, electromotive force and difference of potential, are used with the same meaning; each is said to cause flow of electricity.

4. **Electric resistance** is opposition to flow of electricity. The resistance of a conductor depends on its size and the material of which it is made. If a water pipe is small, it will restrict the flow of water under a given pressure. If the pipe is rough on the inside, it will also restrict the flow. On the other hand, a large, smooth pipe will offer a better path and less resistance to the flow of water. Applying this same thought to an electrical conductor, such as a wire, a small wire tends to restrict, or resist, the flow of electricity to a greater degree than a large wire of the same metal. Also, materials such as copper and silver restrict, or resist, the flow of electricity less than other metals, such as iron. The resistance of a conductor is a quality of the conductor itself and not of the electricity flowing in it or of the electromotive force causing the flow. A device used purposely to introduce resistance in the path of electric current is called a *resistor*, this name referring to the device itself and not to its resistance.

5. The **direction of flow** of electricity is conceived to be from high potential to low potential. For convenience, points of high potential are called *positive* and points of low potential *negative*, and the direction of electric current is always assumed to be from points electrified positively to points electrified negatively.

6. A **drop of potential** occurs along the path of the current and in the direction of the current, just as there is loss of head in a stream of water flowing downwards. The loss of head in flowing water is illustrated by Fig. 1, in which *T* represents a tank of water with a horizontal discharge pipe *E N*, which is provided with open vertical tubes at *a*, *b*, *c*, etc. If the outlet at *N* is closed, the water in all the vertical tubes will rise to the height of the water in the tank; but if the water is allowed to flow freely from the outlet at *N*, then the water in the tubes will settle to the points a', b', c', etc. At *E* the pressure in the horizontal pipe *E N* will support the column of water above *E*; at *a* the pressure supports the column of water $a\,a'$; at *b*, the column $b\,b'$; and so on. That is, the pressure in the horizontal pipe decreases as the outlet is approached. This loss of head and pressure is due to the friction of the water in the pipe. If the pipe is of the same diameter and internal smoothness throughout its length—that is, if it offers uniform resistance to flow of water—the loss of head will be gradual and uniform as the outlet is approached. If the resistance of various sections of the pipe is not uniform, then the losses of head along the various portions of the pipe are proportional, respectively, to the resistances to the flow of water offered by those parts.

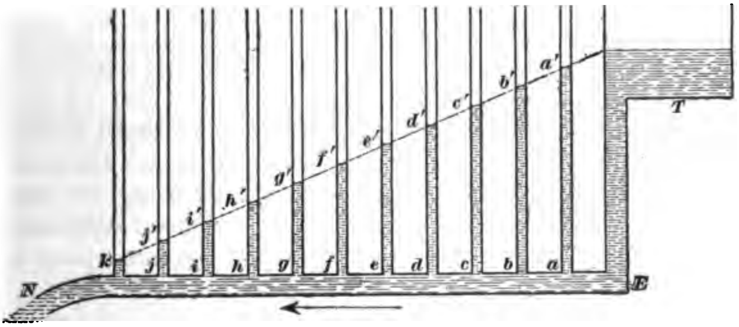


FIG. 1

In like manner, with a given current in a conductor, there is always a drop of potential, due to the resistance of the conductor, and *the drops along the various parts of the conductor are proportional, respectively, to the resistances of those parts.*

TABLE I

ANALOGIES BETWEEN THE FLOW OF WATER AND ELECTRICITY

	Water in Pipes	Electricity in Conductors
I	Difference of level, or head, tends to make water fall from the upper level to the lower level.	Difference of potential, or electromotive force, tends to make electricity flow from a point of high potential to a point of lower potential.
II	If not entirely obstructed, water pressure actually produces a flow of water.	If not entirely obstructed, electromotive force actually produces a flow of electricity.
III	Some of the water pressure is required to overcome the friction of the water against the inside walls of the pipe.	Some of the electromotive force, or electric pressure, is required to overcome the electrical resistance of the conductor and is called *drop of potential*.
IV	Loss of water pressure by friction is directly proportional to the length of the pipe, and inversely proportional to the diameter of the pipe.	Drop of potential due to resistance is directly proportional to the length of the conductor, and inversely proportional to its area of cross-section.
V	No water can flow through a pipe without suffering some loss of pressure; in other words, there is no such thing as an absolutely frictionless pipe.	No electricity can flow through a conductor without suffering some drop of potential; in other words, there is no such thing as an absolutely resistanceless conductor.

7. A tabulation of the analogies of the flow of water in pipes to the flow of electricity in conductors is given in Table I, a careful study of which will do much to assist the understanding of fundamental electrical principles.

PRIMARY BATTERIES

8. A simple way to establish electromotive force is by chemical action. If two plates, one zinc and the other copper, are partly immersed in dilute sulphuric acid, as shown in Fig. 2, one of them will be raised to a higher potential than the other. In other words, a difference of potential will be established between the two plates, and if they are connected by a wire outside the vessel, electricity will flow through the wire from the plate of higher potential to the plate of lower potential. This arises from the chemical action set up within the cell, the acid attacking the zinc and gradually eating it away. The current in this wire is capable of doing work, such as heating the wire or making a very small incandescent lamp glow. Other metals than zinc and copper and other liquids than dilute sulphuric acid may also be used; in general, when any two dissimilar conductors are placed in a solution that attacks one of them, a difference of potential will be set up between the two plates. Such a combination of materials is called a **voltaic cell.** The name *primary cell* is also sometimes applied to the cell to distinguish it from a *secondary cell*, or *storage cell*, in which the plates can be restored to their original state by simply passing a current from an external source through them in the reverse direction.

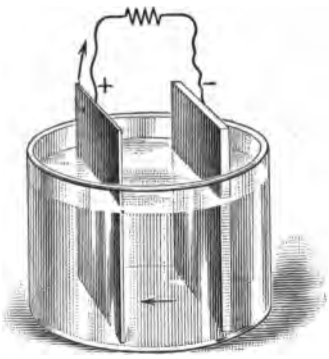


FIG. 2

9. Zinc is the metal that is most commonly used for the element of the primary cell to be consumed, and either copper or carbon for the other element that is not attacked. Whatever the nature of the elements, they are called **electrodes,** and the terminals of these electrodes, to which the connecting wires are attached, are called the **poles** of the cell. The common conception is that electricity always flows through the conductor outside of the cell from the plate or electrode that is not consumed to the plate that is consumed. The terminal attached to the carbon or copper electrode is therefore called the *positive terminal,* and the terminal attached to the zinc electrode is called the *negative terminal.*

The liquid within the cell is called the *electrolyte.* It need not be of sulphuric acid, as any liquid that will attack one of the elements will do. The most common electrolyte used in voltaic cells employed in telephony is sal ammoniac dissolved in water.

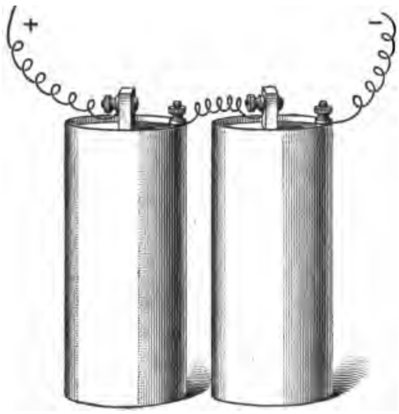


FIG. 3

The dry cell commonly used for energizing electric door bells is a simple voltaic cell having electrodes of zinc and carbon and an electrolyte consisting mainly of sal ammoniac and water. This solution, instead of being present as a free liquid, is held absorbed by blotting paper and other porous material, so as to permit of ready handling of the cell without the danger of spilling.

10. When the desired electromotive force is greater than that of one cell, two or more cells are connected together to form a series, the positive pole of one being connected to the negative pole of the next, and so on throughout the entire number. Such a combination is an **electric battery.** The word battery is sometimes improperly used when a single voltaic cell is meant; a battery is a combination of two or more cells. A battery of two ordinary dry cells so connected is shown in Fig. 3. When cells are connected in series, their electromotive forces are added and the electromotive force of the battery is the sum of the electromotive forces of the cells.

11. In electrical diagrams it is convenient to employ simple symbols for the various pieces of apparatus so as to save time and space in drawing and to avoid confusion. The symbol of a voltaic cell is a pair of parallel lines, one long and thin, representing the positive pole, the other shorter and usually thicker, representing the negative pole. A battery of four cells connected in series is shown by this symbolic representation in Fig. 4.

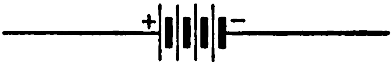


FIG. 4

GENERAL CLASSES OF ELECTRIC CURRENTS

12. Electric currents are of two general classes, *direct current* and *alternating current.*

13. A **direct current** is a flow of electricity always in the same direction. This is the kind of current caused by an electric battery.

A direct current may vary from time to time, in which case it is a *fluctuating*, or *variable*, direct current; but a direct current of constant strength, such as that from a battery in a circuit of constant resistance, is known as a *steady*, or *continuous*, current. If a direct current is made to vary in a periodic manner, being weakened and strengthened at regularly recurring intervals, it is called a *pulsating* current.

14. An **alternating current** is a flow of electricity that reverses in direction, the reversals usually occurring with such great rapidity that the eye can detect no change in the brilliancy of electric lamps lighted by such current. The rate at which the reversals occur is called the **frequency** of the current. The frequency may be constant, as is the case with alternating current employed for light and power; or it may be variable, as is the case with currents used in electrical transmission of speech. Currents with variable frequency reverse at irregular intervals. Frequency may be expressed as the number of reversals, or alternations, in a unit of time or as the number of complete *cycles* per unit of time. A cycle contains two alternations. The usual method of expressing frequency of current in light and power circuits is in cycles per second.

ELECTRICAL UNITS AND RELATIONS

PRACTICAL UNITS

15. The **ampere** is the practical unit of electric current. This unit expresses the flow of a definite quantity of electricity per second. The value, or strength, of an electric current is practically always expressed in amperes. No corresponding unit is in use to express rate of flow of liquids; in this case the rate is expressed as gallons per minute or cubic feet per second.

16. The **volt** is the practical unit of electric pressure, or electromotive force. Volts in electricity may be compared with pounds per square inch in a water pipe or a closed tank. The value of an electromotive force is expressed in volts, and the word *voltage* is frequently used with the meaning *electromotive force in volts*. Thus, the statement that the voltage is 110 means that the value of the electromotive force is 110 volts.

17. The **ohm** is the practical unit of electric resistance. The resistance of conductors is expressed in ohms. No corresponding unit is in use to express the opposition offered by a pipe to the flow of water in it.

OHM'S LAW

18. In a conductor having a given resistance the current is directly proportional to the electromotive force. If the electromotive force is doubled or trebled, the current caused by it will be doubled or trebled. If, on the other hand, the voltage or electromotive force is kept constant, then the current is inversely proportional to the resistance of the conductor; if the resistance is halved, the current will be doubled; if the resistance is doubled, the current will be halved, and so on. This relation may be expressed as follows:

Ohm's Law.—*The current in a circuit is always equal to the quotient derived by dividing the electromotive force by the resistance;* or,

$$\text{current} = \frac{\text{electromotive force}}{\text{resistance}}$$

or by formula,

$$I = \frac{E}{R} \qquad (1)$$

in which I = current, in amperes;
E = electromotive force, in volts;
R = resistance, in ohms.

By transposing terms,

$$E = R\,I \qquad (2)$$

$$R = \frac{E}{I} \qquad (3)$$

that is,
amperes = volts ÷ ohms
volts = ohms × amperes
ohms = volts ÷ amperes

EXAMPLE 1.—What current will result when an electromotive force of 6 volts acts through a resistance of 2 ohms?

SOLUTION.—Here $E=6$, $R=2$, and $I=\frac{6}{2}=3$ amperes. Ans.

EXAMPLE 2.—What electromotive force is required to establish a current of 5 amperes through a resistance of 10 ohms?

SOLUTION.—Here $R=10$, $I=5$, and $E=10\times5=50$ volts. Ans.

EXAMPLE 3.—What is the resistance of a conductor in which 5 volts will establish a current of 10 amperes?

SOLUTION.—Here $E=5$, $I=10$, and $R=\frac{5}{10}=\frac{1}{2}$ ohm. Ans.

CONDUCTORS AND CIRCUITS

MATERIALS USED

19. Materials are widely different in their ability to conduct electricity. Most metals are good conductors, silver being the best, copper next, then gold, aluminum, zinc, platinum, iron, nickel, tin, and lead in the order named. Copper is generally used for conductors, because it is nearly as good as silver and is much less expensive. Aluminum is used to a considerable extent for conductors in long transmission lines. Iron is also used to some extent for conductors in telephone and telegraph lines, because of its cheapness and mechanical strength.

Air, and such materials as glass, porcelain, silk, cotton, dry wood, dry paper, paraffin, beeswax, and rubber are extremely poor conductors, so poor, in fact, that they conduct practically not at all and are termed *non-conductors*, or *insulators*.

20. All of the non-conductors just mentioned are used as insulators in telephony; that is, they are used to so protect the conductors that the electricity in them will be confined to the desired paths instead of escaping to other conductors or partial conductors where it is not wanted. As a familiar illustration of this, iron or copper telephone line wires are supported on glass or porcelain insulators so as to prevent the electricity from leaking away to the ground, as it would do if the wire were supported on materials that had the power of conducting electricity. Another example of the use of insulating material is the wrapping of a copper wire with silk or cotton, or covering it with rubber or dry paper so that the electricity in the wire will not leak off to other objects or from one part of the wire to an adjacent part where the wire is coiled upon itself. Such wire is termed *insulated wire;* the wire is the conductor, and the surrounding non-conducting material is the *insulation.*

ELECTRIC CIRCUITS

21. An **electric circuit** is a conductor or a series of conductors through which electricity may flow. Such a circuit is **closed, completed,** or **made,** when it is continuous so that electricity can flow from a given point around the whole path and back to the starting point. The circuit is **broken,** or **open,** when it forms an incomplete path.

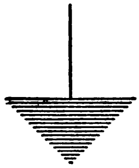


FIG. 5

22. The earth is a vast conductor, and it plays an important part in telephone work, forming part of many telephone circuits. A circuit connected with the earth is said to be a **grounded circuit.** The diagrammatic symbol for an earth, or ground, connection is shown in Fig. 5, and a grounded circuit is indicated in Fig. 6. In distinction from a grounded circuit, a circuit formed entirely of metal conductors, as indicated in Fig. 7, is a **metallic circuit.** By far the larger number of telephone circuits are metallic.

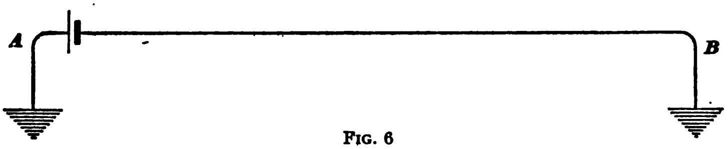


FIG. 6

23. Conductors are connected in **series** when so joined that all the electricity flowing in the path of which they form parts must pass through each conductor, making the current equal in all the conductors. For example, in Fig. 8 an electric cell is represented at *B* and a closed circuit at $c{-}r_1{-}e{-}r_2{-}d$; r_1 and r_2 representing resistors. All the conductors and resistors are in series, because they are in one path; the same current exists in all of them.

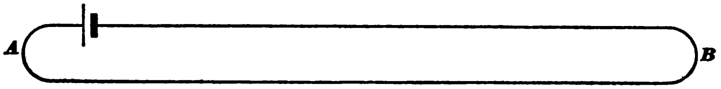


FIG. 7

24. Conductors are connected in parallel, or multiple, when so joined that each will carry part of the total electricity flowing in the circuit of which they are branches. The current in such conductors may or may not be equal, according to whether their resistances are equal. In Fig. 9, resistors r_1 and r_2 are in parallel, or multiple, and each carries part of the total current I in the circuit. Each branch is a *shunt* of the other, or *in shunt* with it, and the two together form a *divided circuit*. A divided circuit may be defined as a circuit containing parallel paths or branches. A circuit shunted by a low-resistance conductor is said to be *short-circuited* by it, and the shunt may be called a *short circuit*, or simply a *short*.

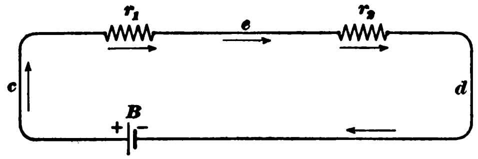


FIG. 8

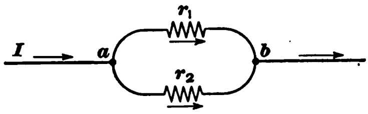


FIG. 9

STATIC ELECTRICITY

ELECTRIC CHARGES

25. **Static electricity** is electricity at rest and it is manifested as *electric charges*. In distinction from static electricity, electricity in motion, manifested as electric currents, may be called *dynamic electricity*, which is the kind already explained.

26. An **electric charge** is an accumulation of static electricity. If an apple is suspended by a silk thread and beaten with a silk handkerchief an electric charge will accumulate on the surface of the apple, owing to the friction of the handkerchief. A spark will jump from the apple to a finger held near it. The friction raises the potential of the surface of the apple until it is enough above the potential of surrounding objects to cause electricity to jump through an air space between the apple and the finger. The flow of electricity ceases almost instantly, for the potentials immediately become equal. Any insulated body may have an electric charge accumulated on its surface.

27. The **electrostatic capacity,** or, more simply, the *capacity*, of a body is a measure of its ability to absorb charges of electricity. The charges may be accumulated, that is, bodies may be charged, in several ways. Friction is one way, as just explained, and another way is shown in Fig. 10. An insulated conducting plate *a* is connected with the positive terminal of a battery of which the negative terminal is connected to the ground. Electricity will flow into the plate until the difference between the potentials of the plate and the ground is the same as the battery voltage. The quantity of electricity that flows into the plate is a measure of its electrostatic capacity.

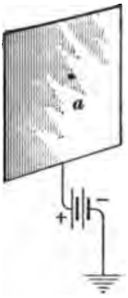


FIG. 10

28. The capacity of a body depends on its surface area and on its nearness to other conducting bodies. Increasing the area of the plate in Fig. 10 would increase proportionately the quantity of electricity that would flow into it at a given voltage. Likewise, bringing another plate connected with the negative terminal of the battery, as at *b*, Fig. 11, near plate *a* increases the flow of electricity, and the nearer the plates are brought to each other the greater will be the flow.

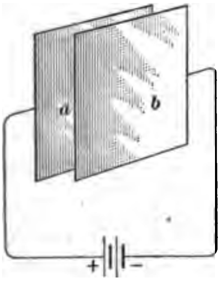


FIG. 11

CONDENSERS

29. A **condenser** is a device consisting of two plates of conducting material separated by an insulating medium called a *dielectric*. In Fig. 11 the dielectric is air. The name *condenser* comes from the fact that such a device has the ability to crowd, or condense, more electricity on a given surface than would be the case if the two plates were widely separated.

The practical unit used in stating the capacity of condensers is the **microfarad.**

30. In addition to the surface area of the plates and their nearness to each other, the dielectric has great influence on the capacity of a condenser. If plates *a* and *b*, Fig. 11, are separated by a plate of glass or hard rubber, the capacity of the condenser thus formed will be much larger than with air as the dielectric, because the electric charges on the two plates have a greater power to react on each other across a layer of glass or hard rubber than across a layer of air of equal thickness.

This quality of insulating materials, which permits charges of electricity to act inductively across or through them, is called *specific inductive capacity.* Of all common insulators, air has the lowest specific inductive capacity. Dry paper has about one and one-half times the specific inductive capacity of air; paraffin, about twice that of air; rubber, three or four times that of air; and mica and glass, about six times that of air. For this reason mica or glass is used as the dielectric in condensers of high electrostatic capacity and air or dry paper in those of lower capacity.

31. The quantity of electricity that will flow into a condenser is proportional to the voltage applied, just as the quantity of water than can be forced into an elastic rubber bag is proportional to the pressure applied. A voltage of 100 will cause ten times as much electricity to flow into a condenser as will a voltage of 10. In each case the charging current continues until the voltage across the condenser terminals equals the applied voltage, just as flow of water into the rubber bag would continue until the pressure in the bag equals the applied pressure. Moreover, the larger the capacity of a condenser, the more electricity will be required to charge it, similar to the fact that a large rubber bag will hold more water than a small one before a given internal pressure is reached. Both the charging voltage and the capacity of the condenser must therefore be known in order to determine the quantity of electricity that it will hold.

32. Condensers were formerly made by laying together a large number of sheets of tin-foil, separated by alternate layers of waxed paper, mica, or other insulating material. The alternate layers of tin-foil projected from opposite sides of the mass, the odd-numbered sheets projecting from one edge being connected together to form one plate of the condenser, and the even-numbered sheets projecting from the other edge to form the other plate. The whole mass was tightly pressed together so as to bring the plates as near to each other as possible. This arrangement is shown diagrammatically in Fig. 12, where *p* represents the tin-foil sheets, *i* the insulating materials between them, and *T T* the terminals. It should be noticed that there is no electrical connection between the two sets of plates connected to the two terminals *T T*.

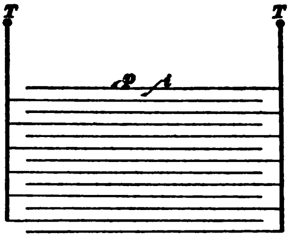


FIG. 12

An enormous number of condensers are required in telephone work and the form just described is too large and too expensive to meet the requirements. The condenser now commonly used in telephone work consists of two long strips of tin-foil with intervening strips of paper, all rolled together in a compact mass in such a way that the two strips of tin-foil are insulated from each other by the paper throughout their length. The symbols for condensers generally used in diagrams of telephone circuits are shown in Fig. 13.

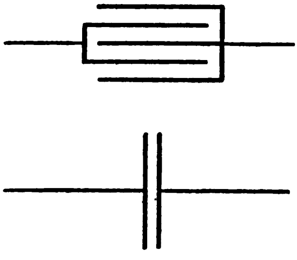


FIG. 13

33. The time required to charge a condenser is only a minute fraction of a second; that is, the difference of potential between the plates almost instantly becomes equal to the difference of potential, or electromotive force, of the charging current. If the charged condenser is short-circuited, that is, if its terminals are connected with each other, electricity instantly flows between the plates until their potentials are again equal, the flow in this case being opposite to the direction of the charging current and also of extremely short duration. Both when charging and discharging, however, there is momentary flow of electricity, and if the charges and discharges are frequent enough, the flow will be appreciable as alternating current.

34. A condenser in an alternating-current circuit receives electricity while the electromotive force at the condenser terminals is rising and gives it back to the circuit while the electromotive force is falling. Although the circuit through the condenser is open because of the insulation between the plates, alternating current is thus set up in the conductors leading to and from the condenser. A condenser in a telephone circuit, therefore, does not interfere with flow of electricity as fluctuating current, such as voice currents or as alternating current used for signaling purposes; but it does prevent flow of direct-current electricity. This fact is of great importance in telephone work.

MAGNETS AND MAGNETISM

GENERAL PROPERTIES OF MAGNETS

35. A **magnet** is a body that has the property of attracting pieces of iron and steel. If a bar of steel is rubbed by a magnet, the bar becomes a magnet and has the power of attracting other pieces of iron or steel. If this bar of steel is tempered hard, it will retain this magnetism almost indefinitely, and for this reason it is commonly called a **permanent magnet.** Any magnetized piece of iron or steel that retains its magnetism is a permanent magnet.

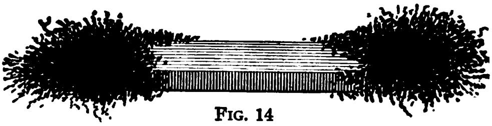


FIG. 14

If a permanent bar magnet is dipped into iron filings, the filings will be attracted toward the two ends and adhere there in tufts, as shown in Fig. 14; toward the center of the bar there

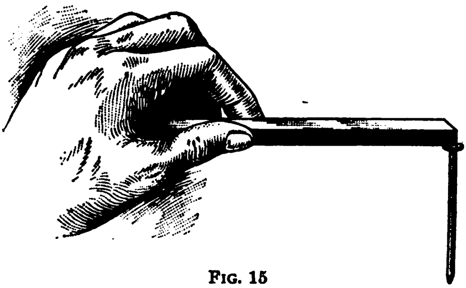


FIG. 15

is no attraction and the filings will not adhere there. If one end of a magnetized bar of steel is brought near to a bit of soft iron, the iron will be attracted and, if not too heavy, will be lifted by the bar and will adhere to it, as shown in Fig. 15. Exactly the same attraction will be exhibited by either end of the bar magnet toward such a piece of soft iron. The center portion of the bar will, however, exhibit no such attraction. That part of the magnet where there is no apparent magnetic action is the **neutral portion,** or *neutral zone*, and the parts at or near the two ends which do exhibit the power of attraction are the **poles.**

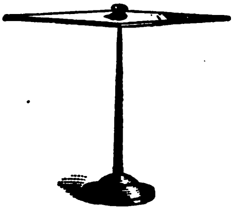


FIG. 16

36. A compass needle, one form of which is shown in Fig. 16, is in reality a small permanent magnet, pivoted at its center so as to swing freely in a horizontal plane. Such a needle always comes to rest with one end, called the *north pole*, pointing north and the other, called the *south pole*, pointing south.

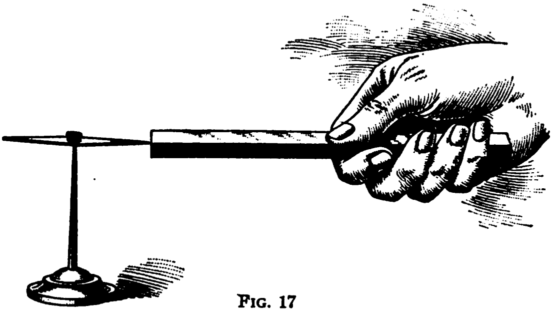


FIG. 17

If forcibly turned from this position and then released it will immediately return to the same position, showing an invisible attraction between some parts of the earth and the poles of the magnet.

37. If one end of a bar magnet is brought near a compass needle, as in Fig. 17, the needle will be deflected from its north-and-south position, one end being attracted by the permanent magnet and the other end repelled. If the other end of the bar magnet is presented to the compass needle, the end of the needle which was formerly attracted will now be repelled. The two ends of the bar magnet, although acting alike in attracting iron filings and pieces of soft iron, must, therefore, be in some way different from each other, since one end will attract only the north pole of the compass needle, while its other end will attract only the south pole.

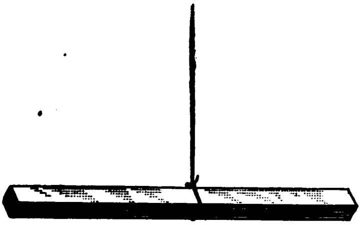


FIG. 18

This difference between the two ends of a permanent bar magnet will be further manifested if the bar is suspended at its center by a piece of fine thread, as shown in Fig. 18. The bar will now be free to assume its own natural position and will finally come to rest pointing north and south exactly as in the case of the compass needle; the end pointing north is called the north pole and the other end the south pole.

38. If the ends of the bar magnet are marked by the letters N and S to identify the north and south poles, and the magnet is again presented to the compass needle, it will be found that the north pole of the magnet attracts the south pole of the compass needle and repels the north pole, and that the south pole of the magnet attracts the north pole of the needle and repels the south pole. These experiments show that two *like poles repel each other and unlike poles attract. This is always true in the action of magnets of any kind.*

39. The reason why the compass needle or any freely suspended bar magnet takes a position with its north pole pointing north is that the earth itself is a great magnet, whose magnetic poles coincide nearly, but not quite, with the true geographical north and south poles. The laws of attraction and repulsion, just demonstrated by ordinary bar magnets, apply equally well to the attraction and repulsion between the earth's poles and the poles of the compass needle, or of any other magnet. There is, however, one apparent inconsistency; like poles repel, yet the north pole of the compass needle is attracted by the north pole of the earth. As a matter of fact, the north pole of the compass needle is of opposite polarity to the north pole of the earth, otherwise these two poles would not attract each other. It would be more correct to call the north-seeking pole of the compass a south pole, or to call the earth's north magnetic pole a south pole; but the common custom is otherwise, and the confusion is one of names only.

40. The common **horseshoe magnet,** Fig. 19, is simply a bar of steel bent into the shape indicated and then hardened and magnetized. Usually a piece of soft iron, called the *armature*, is placed across the poles, where it is held by magnetic attraction. When made in this form, both poles may act on a single armature and the magnetic attraction is much stronger than in the case of a bar magnet.

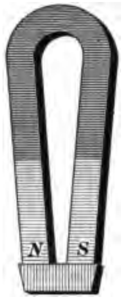


FIG. 19

41. The space surrounding a magnet in which any magnetic substance will be attracted or repelled is its **magnetic field.** Magnetic attractions and repulsions are found to act in definite directions, and along imaginary lines, called *lines of magnetic force*, or simply *lines of force*. A good idea of the field of force about a bar magnet may be shown by placing a piece of paper over a magnet and sprinkling fine iron filings over the paper. If the paper is then gently tapped with a pencil or the finger, the filings will arrange themselves in accordance with the directions in which the magnetic force acts, that is, with the lines of magnetic force traversing the field. In the case of a bar magnet lying on its side, the filings will arrange themselves in curved lines, extending from the north to the south pole, as shown in Fig. 20. If the magnet is held perpendicular to the paper the filings will arrange themselves in radial lines, as indicated in Fig. 21.

42. The **magnetic flux,** or simply the *flux,* of a magnet or of a magnetic field is the total number of lines of force in it, and the **magnetic circuit** is the path traversed by these lines of force. The magnetic force of a magnet always acts in a complete circuit, which includes the iron or steel of the magnet and the air or other medium surrounding the poles. Each line of force is assumed to pass out of the magnet at the north pole,

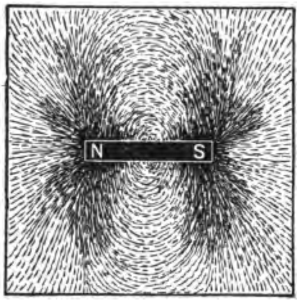


FIG. 20

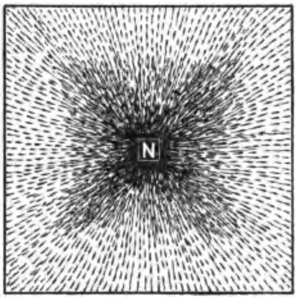


FIG. 21

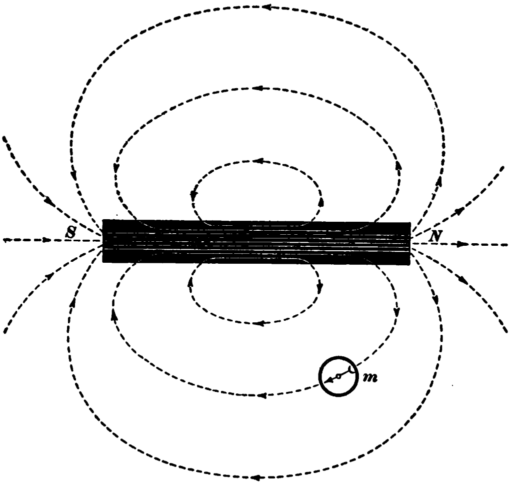


FIG. 22

through the air or other medium, to the south pole, and thence through the magnet to the north pole. This direction is merely assumed, but the assumption leads to no error and is helpful in studying magnetic action. Fig. 22 represents a bar magnet and a few of its lines of force, the assumed direction of which is indicated by arrowheads and a compass *m*.

43. Magnetism may be **induced** in a magnetic substance, or produced by **magnetic induction,** by merely bringing the substance into a magnetic field. For example, if a piece of iron is brought into such a field, the lines of force crowd into the iron. If the piece is free to rotate, it will come to rest with its greatest length in the direction of the lines of force. Iron or steel thus traversed by the lines of force of another magnet becomes a magnet itself, as is readily demonstrated by the experiment shown in Fig. 23. A chain of ordinary steel pens is suspended from the pole of a permanent magnet, and each pen, being traversed by the lines of force emanating from the magnet, becomes a magnet to a sufficient extent to bear the weight of the pens below it. Each pen thus exhibits magnetic properties, its magnetism being induced, or produced by magnetic induction.

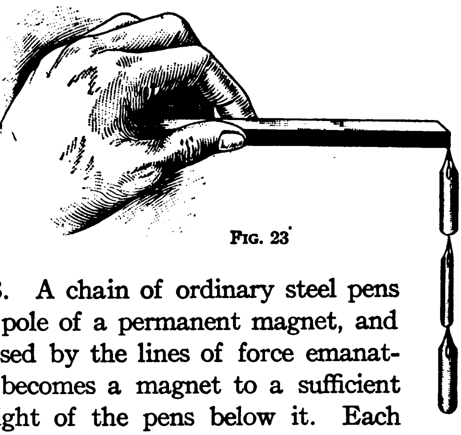


FIG. 23

44. **Residual magnetism** is the magnetism remaining in iron or steel after the magnetizing influence is no longer active. These two materials differ in their ability to retain magnetism, steel being much more retentive than iron, especially if the iron is of a soft grade. The pens of the experiment just described will probably show some power of attracting each other, even after the permanent magnet is removed. Very soft iron, on the other hand, although easily magnetized, will retain none of its magnetism after the magnet or other magnetizing source is removed. Poor grades of iron—that is, iron that is neither pure nor very soft—will retain some magnetism after the magnetizing source is removed, behaving in this respect somewhat like steel.

RELATIONS BETWEEN ELECTRICITY AND MAGNETISM

MAGNETIC EFFECT OF ELECTRIC CURRENT

45. Electricity and magnetism are closely related in action. A current of electricity always establishes around itself a magnetic field, and this fact is of great importance in telephone work. If a wire carrying a current of electricity is brought near a compass needle, as in Fig. 24, the needle will be deflected from its north and south position and will tend to assume a position at right angles to the wire. No such influence is shown, however, when the current ceases. Evidently then, the current in the wire has some such property as a magnet, since it is able to move a compass needle from its normal position. In fact, a wire carrying a current is surrounded by a magnetic field. This may be demonstrated by passing a wire vertically through a horizontal sheet of paper, sprinkling iron filings on the sheet of paper, and gently agitating the

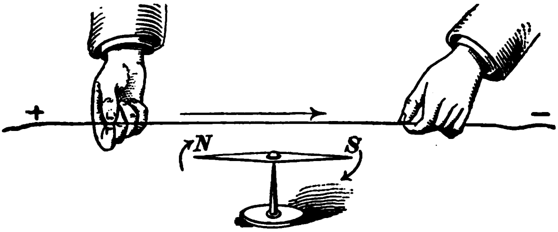


FIG. 24

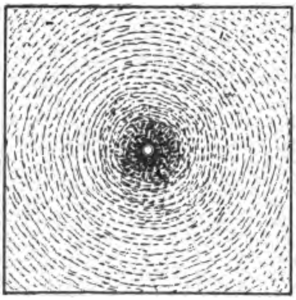


FIG. 25

paper. The filings will arrange themselves about the wire in circular rows, as indicated in Fig. 25.

It is common to conceive this field of force about a wire carrying a current as being in the nature of a magnetic whirl about the conductor, the field of force being made up of magnetic lines acting in circles, as suggested diagrammatically in Fig. 26. If the direction of the current is reversed, the direction of the magnetic lines will be reversed, as may be observed by the action of the compass needle.

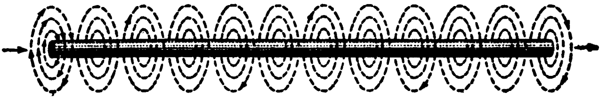


FIG. 26

46. A very simple way of remembering the relation between the direction of the flow of current in a conductor and the direction of the lines of force surrounding it is to bear in mind the relation between the movement of a right-handed screw and the direction in which the screw must be turned in order to cause the movement. In Fig. 27 an ordinary screw is being driven into a board by means of a screwdriver. In order to make the screw move in the direction of the straight arrow, the screwdriver must be turned as shown by the curved arrow. If the movement of the screw into the board represents the direction of the current in a conductor the rotary movement of the screwdriver represents the direction of the lines of force surrounding the conductor.

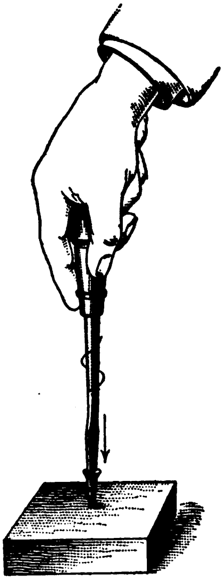


FIG. 27

ELECTROMAGNETIC SOLENOID

47. An electromagnetic solenoid is a coiled conductor in which electricity is flowing; the word *solenoid* alone is frequently used in referring to an electromagnetic solenoid. If the piece of wire shown in Fig. 26 is bent into a single loop with its ends connected to a voltaic cell, as shown in Fig. 28, all of the lines of force surrounding the conductor will thread through the loop in the same direction. By bending the conductor into a long helix of several loops, as in Fig. 29, the effect is the same as piling a number of loops on each other, and some of the lines of force will thread through all of the loops in one direction. In this case, the lines of force around each loop tend to combine with those around each adjacent loop, thus forming longer loops, each surrounding several adjacent turns of wire. If the helix is more tightly coiled, with the turns close together, the lines of force, or whirls, about each individual turn will almost disappear, being replaced by the longer lines of force threading through the entire helix and returning through the air, outside of the helix. In other words, the whirls surrounding each individual wire, as in Fig. 28,

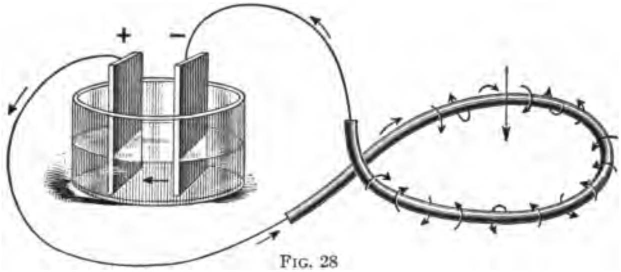


Fig. 28

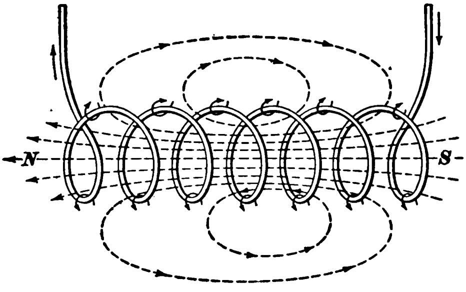


Fig. 29

stretch so as to include all of the wires of the spiral, the result being a series of elongated whirls, or lines of force, all passing through the coil in one direction and back outside of the coil in the other direction. A field of force thus exists about the helix which has the same characteristics as that surrounding the bar magnet or the electromagnet. The presence of magnetism can be readily tested by its influence on iron filings and on a compass needle. The solenoid manifests the magnetic properties of a permanent magnet.

ELECTRICAL MEASURING INSTRUMENTS

48. A **galvanometer** is a very sensitive electrical measuring instrument that depends for its action on the influence exerted by an electromagnetic solenoid on a magnetic needle. A simple form of galvanometer is shown in Fig. 30, the coil here being square in form. When this particular instrument is in use the coil should be placed so that its plane is vertical and in a north-and-south direction; that is, so that it coincides with the direction of the needle when the coil is carrying no current. A current in the coil then causes the needle to deflect toward a position at right angles to the plane, and the extent of the deflection depends on the strength of the current, or is proportional to it.

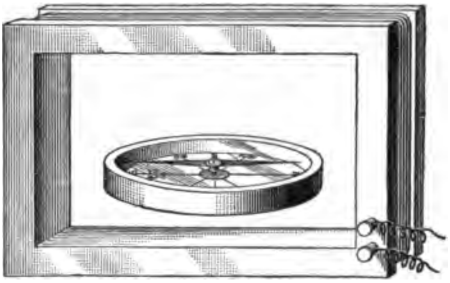


FIG. 30

In the simpler forms of galvanometers the needle carries an agate cup into which extends a fixed pivot; in the more delicate forms the needle is suspended by a silk or quartz fiber or a very thin strip of metal.

49. Galvanometers are used to detect the presence of electric current or to indicate its strength or to indicate the values of electromotive forces. Instruments employing the principle of the galvanometer and arranged especially for indicating the strengths of electric currents, that is, to measure them, are called *ammeters*. Similar instruments arranged to indicate values of electromotive forces are called *voltmeters*. Such instruments are much used in telephone work.

ELECTROMAGNETS

50. An electromagnetic solenoid with an iron core is an **electromagnet** and shows all the characteristics of a permanent magnet; the solenoid is the *magnetizing coil*. Ordinarily a piece of soft iron shows no magnetic qualities, but when placed inside an electromagnetic solenoid it becomes a magnet; that is, magnetism is induced in it. It will attract and hold pieces of iron, as shown in Fig. 31, and will influence the poles of a compass needle, as shown in Fig. 32; one end of the electromagnet will attract the north pole of the magnet and repel the south pole, while the reverse is true of the other end of the electromagnet.

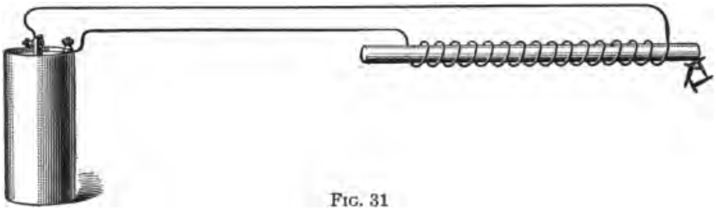


FIG. 31

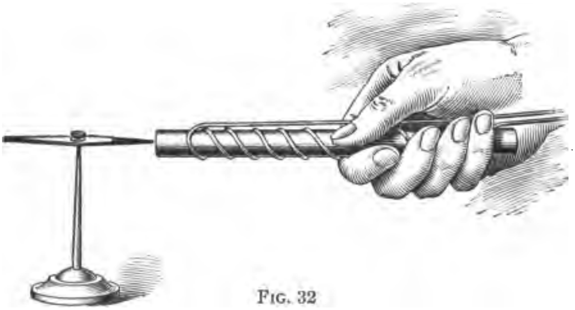


FIG. 32

51. If the current ceases in an electromagnet the core loses some or possibly nearly all of its magnetism; a change of current in the coil causes a change of the magnetism; reversal of the current causes reversal of the polarity of the core. If an electromagnet could be suspended by its center so that it could turn freely it would come to rest in a north-and-south direction, similar to a compass needle. If the direction of the current in the coil is reversed the electromagnet will reverse its direction, the north pole now becoming the south pole and vice versa.

52. An iron core greatly increases the effect of current in a solenoid because iron affords a very much better path for the lines of force than air or any other non-magnetic substance, such as wood, brass, copper, or hard rubber; that is, iron offers lower **reluctance** to magnetic flux than do other substances. The result is, therefore, that when an iron core is placed within an electromagnetic solenoid the number of lines of force will be greatly increased, with the result that the magnetic pull of the solenoid will be much stronger than it would be without the iron core.

The number of lines of force a given current will set up in any coil may be still further increased by employing iron instead of air for the return path of the lines of force outside the coil. The number of lines of force a current of given strength can set up in a coil will increase as the amount of iron in the magnetic circuit is increased. For this reason the cores of electromagnets are often bent into horseshoe form so that the return path for the magnetic lines will be mainly through iron rather than through air. The length of the magnetic circuit of a straight-bar magnet 6 inches long is 6 inches through steel and at least 6 inches through air. If the same bar is bent into horseshoe form, as in Fig. 19, with its poles $\frac{1}{4}$ inch apart, the length of the magnetic circuit will be 6 inches through steel and only $\frac{1}{4}$ inch through air. If an armature is provided, the path will be entirely through steel and iron. As hard steel is over one thousand times as good a conductor of magnetic lines as air, the shortening of the path through the air makes possible a very great increase in magnetic lines through the circuit.

53. The **magnetizing coil** of an electromagnet usually consists of a large number of turns of insulated wire, that is, wire covered with insulating material, such as silk, cotton, or enamel. If the wire and core were bare, the current would take a shorter and easier path from the wire to the core, or from one turn of wire to adjacent turns. This would defeat the purpose of the structure, for in order to produce an electromagnet it is necessary that the electricity be made to travel around and around the core, through all of the convolutions of the wire. The common practice is to insulate the core itself with a layer of paper or cloth, and to make the heads of the spool either of insulating material, or, if of metal, to provide them with a layer of insulating material on their inner faces.

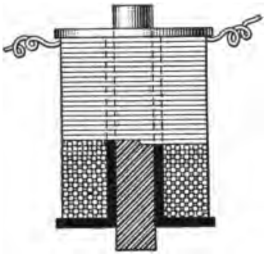


FIG. 33

54. The forms of electromagnets are many and varied. The simplest form is the straight-bar magnet, or single-coil magnet, as shown in Fig. 33, in which the lower part of the electromagnet is represented in section. The most convenient form for a great variety of uses is the horseshoe, or **U**-shaped, magnet illustrated in principle in Fig. 34. This sometimes consists of a bent bar of soft iron and two magnetizing coils, one on each end, or limb, of the magnet. The direction of the current in the windings on a horseshoe magnet is in opposite directions around the two legs, that is, clockwise around one leg and counterclockwise around the other, as is indicated in the sectional view. In this way a north pole is produced at one end of the core and a south pole at the other end.

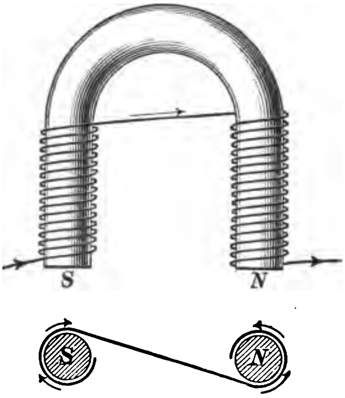


FIG. 34

For convenience in manufacture, the **U**-shaped electromagnet, or two-coil magnet, is usually made in parts, as shown in Fig. 35; namely, two straight round-iron cores *M*, magnetizing coils *c*, and a straight bar, or yoke, *b* of iron joining the two cores together. The core *M* and its coil are shown in section, that is, as they would appear if cut on a plane passing through the axis of the core. The heavy black lines represent the insulating spool on which the wire is wound.

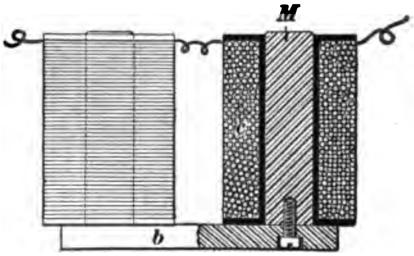


Fig. 35

Another common form of electromagnet is the ***iron-clad magnet***, of which Fig. 36 shows one of the simplest forms partly in section to reveal the construction. In this particular form the single core *M* is fastened to the bottom of an iron cup *S*. The magnetic circuit is completed through the shell, which completely surrounds and protects the coil.

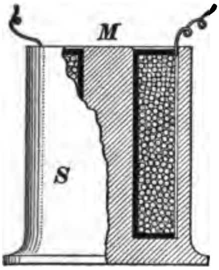


Fig. 36

55. The pull of a permanent magnet can be varied by the use of an electromagnetic solenoid, and this fact is of great importance in telephony. The solenoid is placed around the magnet, and the lines of force set up by the current in the solenoid will either increase or diminish the strength of the permanent magnet, according to whether they are in the same direction or are opposed to those of the permanent magnet. If the current in the coil is made to vary, the magnetism set up by the coil will vary in accordance with it, and this magnetism will be either added to or subtracted from the magnetism of the permanent magnet, thus causing it to exert a varying pull on its armature.

ELECTROMAGNETS IN TELEGRAPHY

56. The theory of electricity and magnetism has now been sufficiently developed to make possible an understanding of some of the principal uses of electromagnetism in telegraph and telephone work. Perhaps the simplest illustration is the sounder used in telegraphy, an example of which is shown in Fig. 37; a two-coil electromagnet with a soft-iron armature causes a lever to strike alternately against two adjustable stop-screws, which limit its up-and-down motion. A spring normally keeps the lever in its upper position. When the coils of the magnet are energized, the armature is attracted and the lever is pulled down against its lower stop, and when the current ceases the spring pulls the lever back against its upper stop.

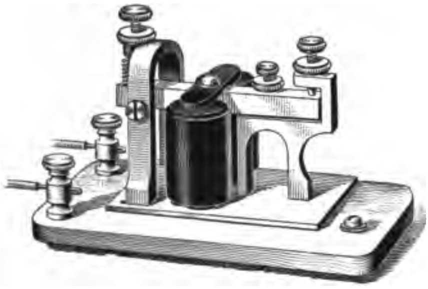


Fig. 37

When this sounder is connected in circuit with a battery and a device for opening and closing the circuit, as shown in Fig. 38, signals can be transmitted from one point to another. When the key is depressed so as to close the circuit, the current set up by the battery energizes the magnet coils of the sounder, causing the attraction of the armature. The sounder lever is thus moved forcibly downwards against its lower stop, causing a sharp click. When the pressure on the key is released, the circuit is opened, the coil deenergized, and the sounder lever allowed, under the influence of its spring, to come back to its normal, or raised, position, thus producing another click. The sounder lever at the receiving end of the line is thus made

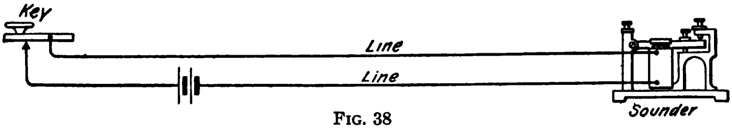


Fig. 38

to imitate the up-and-down motions of the key at the sending end, and by the resulting clicks the listening telegraph operator is enabled to understand the message transmitted by the operator manipulating the key.

This simple arrangement of a telegraph sounder, key, and battery was the first adaptation of electricity that went into widespread use in the service of man. It is the telegraph invented by Morse in 1838, and still used more widely than any other system of telegraphy.

INDUCED ELECTROMOTIVE FORCES

ELECTROMAGNETIC INDUCTION

57. Electromagnetic induction is the name given the process of inducing electromotive force in a conductor by varying the number of lines of force surrounding it. If the circuit of the conductor is complete, electricity will flow as the result of such induction. This fact is the exact converse of the phenomenon previously explained that a current of electricity in a conductor causes magnetic lines of force to surround the conductor. The principle of electromagnetic induction is employed in the generation of electricity for lights, railway work, and so on.

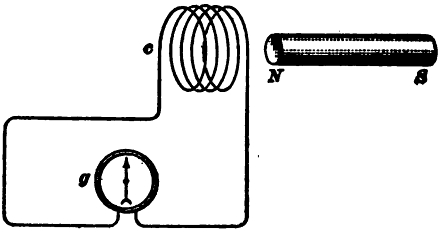


FIG. 39

The experiment illustrated in Fig. 39 demonstrates this principle. A galvanometer g is connected in the circuit with a coil c. If one end of the magnet NS is suddenly thrust into the coil, the galvanometer needle will be momentarily deflected in one direction. Sudden withdrawal of the magnet will cause a deflection of the needle in the opposite direction. Any movement of the magnet in the vicinity of the coil, or the coil in the vicinity of the magnet, in such a way as to vary the number of lines of force passing through the coil, will cause a current in the coil, as will be indicated by the deflection of the needle. This current continues only while such movement is taking place. *Its direction depends on the direction of the lines of force threading the coil and on whether their number is being increased or diminished. Its strength depends on the rate at which the number of lines is being changed.*

This experiment shows that magnetism can be made to produce electricity, and experiments described in connection with the electromagnet show that electricity can be made to produce magnetism. These transformations of electric energy into magnetic energy, as in the case of the electromagnet, and of magnetic energy into electric energy, as in the experiment just described, are probably the most useful phenomena in the whole realm of electricity.

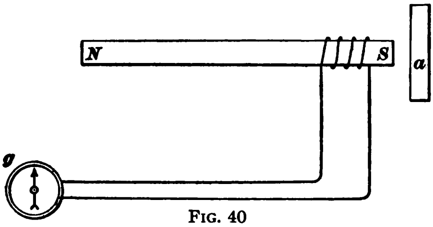


Fig. 40

58. There are many ways of varying the number of lines of force that thread a coil of wire, one of which is shown in Fig. 40. In this, NS is a permanent bar magnet on one end of which is a coil of fine wire, connected in circuit with a galvanometer g. In front of the magnet is an armature a of soft iron. If the iron armature is suddenly moved away from the magnet pole, the number of lines of force passing through the coil will be diminished, because the iron of the armature has been moved farther out of the magnetic circuit. As a result of this decrease in the number of lines, a current in one direction will be set up in the coil, and the galvanometer needle will be deflected in the corresponding direction. If the iron armature is suddenly moved toward the magnet pole, the number of lines of force passing through the coil will be increased, because of the better magnetic circuit. This will result in another current in the opposite direction to the first, deflecting the galvanometer needle opposite its former direction. If this iron armature is rapidly vibrated back and forth in front of the magnet pole, electromotive forces will be induced in the coil and currents will be established first in one direction and then in the other. In other words, an alternating current will result.

MUTUAL INDUCTION

THEORY

59. Mutual induction is the name given to the influence exercised on the electric condition in a conductor by an electric current in a neighboring conductor. Fig. 41 represents two conductors lying side by side and parallel, one of them, *a b*, receiving current from a battery *B*. The circuit also includes a resistance *r* shunted by a switch *k*. In series with the other conductor *c d* is a galvanometer *g*. The current in conductor *a b* causes a magnetic whirl to surround both conductors, and any change in this magnetism induces electromotive force in the neighboring conductor *c d*. For example, closing the switch *k* short-circuits, or bridges, the resistance *r*, increases the current in the conductor *a b*, increases the magnetic flux surrounding both conductors, and causes a current in the circuit through the galvanometer, as will be indicated by a deflection of the galvanometer needle. Opening the key causes

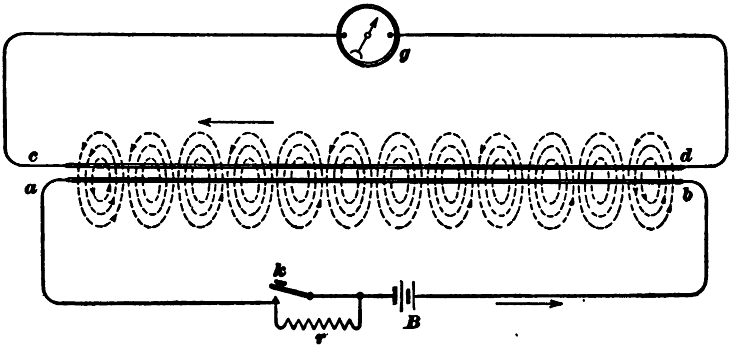


FIG. 41

a deflection in the opposite direction, because the battery current and the magnetic flux surrounding the conductors decrease. In each case the deflection is only momentary, because the induced current in the galvanometer circuit lasts only while the magnetic flux is changing.

This experiment shows that whenever two conductors lie close together and parallel with each other a change in the current in one of them induces an electromotive force in the other and a current is thus set up in the second conductor if its circuit is closed. The induced current will be in one direction when the current in the first conductor is increased, and in the opposite direction when it is diminished. The strength of this induced current will depend on the rate at which the current in the first conductor changes.

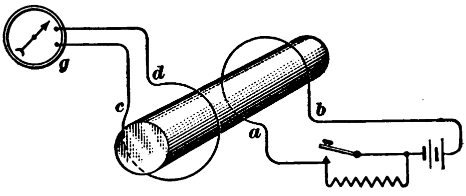


Fig. 42

60. If the two conductors *a b* and *c d* are wrapped around an iron core, as in Fig. 42, changes in the current in *a b* will cause much larger induced current in *c d*, because the number of lines of force surrounding the two conductors will be larger and the change in this number larger owing to the presence of iron in the magnetic circuit.

INDUCTION COILS

61. The **induction coil** operates on the principle of mutual induction, as just explained. An elementary form of induction coil is indicated in Fig. 43. Here conductors *a b* and *c d* are wrapped many times around an iron core, thus greatly increasing the effect of the battery current in setting up lines of force and also increasing the effect in inducing current in the conductor *c d*. The winding that receives current from an external source is the **primary** and the winding in which electromotive force is induced is the **secondary** of the induction coil. A switch *k* serves to open and close the primary circuit, and each movement of this switch will cause a deflection of the galvanometer needle.

62. Induction coils are much used in telephony. As usually made, the core consists of a bundle of soft-iron wires. The primary and secondary windings are insulated from each other and from the core. The sizes of wire used in the two windings and the number of turns in each depend on the service the coil is to perform. If the size and the number of turns are the same in both windings the ratio of transformation is as 1 to 1; that is, the voltage across the terminals of the secondary winding will be practically the same as the voltage across the terminals of the primary winding. If the secondary winding has ten times as many turns as the primary, the ratio of transformation is as 1 to 10, the secondary voltage being then ten times the primary voltage.

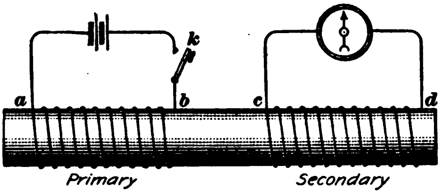


FIG. 43

63. The functions of the windings of such a coil can be reversed; that is, the winding with the greater number of turns can be used as the primary and the other winding as the secondary. In either case, the ratio between the primary and secondary voltages will be approximately the same as the ratio of the number of turns. A coil used to obtain increased voltage is called a *step-up coil* and a coil used to obtain decreased voltage is called a *step-down coil.* Some losses occur in every coil, so that the output, represented by the product of volts and amperes, is somewhat less than the input.

64. The induction coil furnishes a means for obtaining a very wide range of electromotive forces. In the case of large induction coils used for X-ray work, for instance, a pulsating current from a battery of only a few volts in the primary winding, which has but few turns of coarse wire, will induce in the secondary winding, which has many turns of very fine wire, alternating currents of several hundred thousand volts. In this case, as before, the amount of current in the secondary winding will be exceedingly small, so that the energy is not increased.

65. The construction of an induction coil of a type commonly used in telephony is shown by the sectional view, Fig. 44. The spool of the coil consists of a fiber or paper tube, filled with a bundle of very soft iron wires. On the ends of the tube are glued two square heads of wood or fiber. On the tube is wound a few layers of rather coarse insulated wire. Over this coil is then wound several layers of waxed paper or cloth to afford additional insulation between the primary and secondary windings, and on this is wound the other coil, consisting of a much greater number of turns of comparatively fine wire insulated with silk or enamel. Over the outside of this, for purposes of appearance and protection, is wound a layer of bookbinder's cloth. In order to prevent breaking the wires that extend from the coil and to facilitate their connection with other wires, they are usually soldered to metal terminal clips, mounted either on the heads or on the case, as convenience may require.

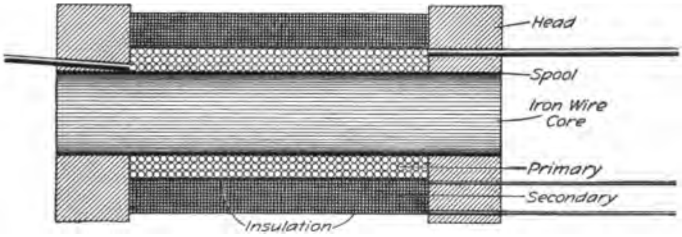


FIG. 44

SELF-INDUCTION

THEORY

66. Self-induction is the name given to that property of a circuit by virtue of which changes of current in the circuit influence the flow of electricity in the circuit itself. This property may be explained by referring to Fig. 45, which shows a section of a coiled conductor and indicates by dotted lines the magnetic field surrounding the conductors when electricity from a battery flows in them. While the current is constant the number of lines of force surrounding the conductors remains constant, and the strength of the current is determined by Ohm's law, namely, $I = E \div R$.

Any change in the number of lines of force, however, induces an electromotive force in the coil, no matter what causes the change. Changing the current in the coil changes the number of lines of force surrounding it and induces an electromotive force in the coil, just as it would in another coil in the same field. Electromotive force induced in a circuit by changes in the current in the same circuit is called **electromotive force of self-induction.** In principle, this property is precisely the same as the mutual induction that occurs between neighboring conductors. If the induction is between turns in the same circuit or coil it is called self-induction.

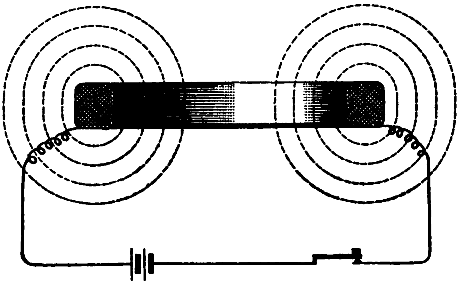


FIG. 45

67. Electromotive force of self-induction is always in a direction to oppose change of current in the circuit. It is therefore usually called *counter electromotive force of self-induction.* It is not, however, large enough to prevent the change and therefore acts only to retard it. If the current is reduced, thus decreasing the number of lines of force, the electromotive force of self-induction tends to retard the reduction; if the current is increased in value, self-induction tends to retard the increase. The more sudden the change of current the larger is the electromotive force of self-induction.

68. Reactance and **impedance** are properties of circuits caused or influenced by self-induction. When the switch in Fig. 45 is closed the current in the circuit does not increase instantly to full value, and when the switch is opened the current tends to continue for an instant, possibly causing a spark across the break made by opening the switch. If the switch is closed and opened rapidly the current changes do not occur in exact synchronism with the switch movements but lag slightly. Nor does the current reach the full maximum value that it would reach if the switch remained closed for an appreciable time. The more rapid the switch movements are made the more will the current lag and the less will be its maximum value.

The property of a circuit whereby the variations of alternating current lag behind the corresponding variations of the electromotive force causing the current is called its *reactance*, and this property combined with the resistance of the circuit gives the *impedance* of the circuit, or its total opposition to the flow of electricity as alternating or varying current. The greater the frequency of the current changes, the greater is the reactance and the impedance of the circuit. Impedance to varying currents may be very high, whereas the resistance of the same circuit to direct currents is comparatively low.

IMPEDANCE COILS

69. Impedance coils, also called *retardation coils*, are constructed particularly with the view of restricting the flow of electricity as alternating, pulsating, or variable current through them, while they may offer low resistance to the passage of continuous current. Such coils play an important part in telephony.

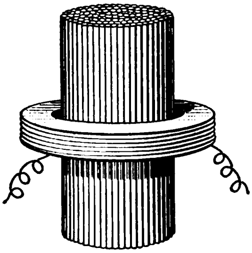


FIG. 46

The self-induction of the coil shown in Fig. 45 would be very greatly increased if a bundle of soft-iron wires were placed through it, as in Fig. 46, because a given magnetizing current would then be able to set up a greatly increased number of lines of force. If the bundle of soft-iron wires were replaced by a bundle of the same diameter, wound into the form of a ring, as in Fig. 47, the self-induction of the same coil would be still further increased, because the reluctance of the magnetic circuit is still further decreased.

Again, if the number of turns of the conductor in the coil were increased, the self-induction would be greatly increased; the magnetizing current would then pass more times around the core and thus produce in it greater magnetization, and the varying magnetic field would thread through more turns.

The greater the self-induction of a coil the greater will be its reactance and its impedance to an alternating or variable current. Consequently, when a coil of large impedance is desired, it is usually made with a large number of turns, and with a large amount of iron in the magnetic circuit.

70. In telephone work, coils are frequently required that allow steady currents to pass with comparative freedom and yet offer very large opposition to the flow of rapidly varying currents. Such coils are made of large wire so as to present low resistance, and the wire is wound on heavy closed magnetic circuits so as to offer the best possible paths for the lines of force. Such an impedance coil may have a resistance to direct, steady currents of only a few ohms, while it will offer an impedance of thousands of ohms to high-frequency variable currents. This property of impedance coils makes them very important in telephone work.

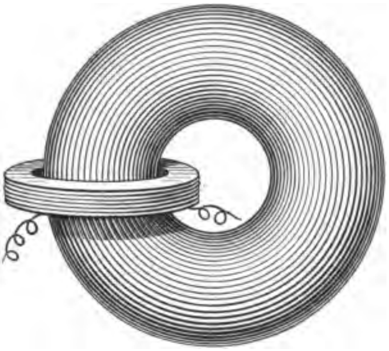


FIG. 47

71. A **non-inductive circuit** is a circuit having no inductive reactance; that is, changes of current cause no counter electromotive force of self-induction. A resistance having these characteristics is called a *non-inductive resistance*. Electric circuits and resistances are very rarely entirely non-inductive, but they can be made nearly so. A straight wire surrounded by air, the filament of an incandescent lamp, a piece of arc light carbon, two plates of metal immersed in water, etc. are examples of resistances that are practically non-inductive.

72. An **inductive circuit** is a circuit that has the property of self-induction. Circuits that include coils of wire such as electromagnet coils and impedance coils are inductive circuits. The flow of electricity through a non-inductive circuit is according to Ohm's law, whether the current be constant and direct, alternating, or varying in value.

Ohm's law applies also for steady currents in inductive circuits, but not for varying currents. Circuits for varying currents should be as free as possible from magnet coils or other inductive devices.

PRINCIPLES OF TELEPHONY

ACOUSTICS

CAUSE AND NATURE OF SOUND

1. The telephone is fundamentally an electrical invention, but in order to understand it, some knowledge of the principles of *sound*, in addition to those of *electricity*, is essential. **Acoustics** is the science pertaining to sound.

2. For the purpose of telephony, **sound** may be said to be the sensation produced by vibrations of air on the drum of the ear. When one man speaks to another, the speaker sets in motion a series of air waves, which strike against the delicate membrane of the listener's ear and produce the sensation of sound.

A very rough idea of the way in which sound waves in air affect the drum, or diaphragm, of the ear may be obtained by imagining a thin plate placed in an upright position in a vessel of perfectly still water. A pebble dropped into the water will set up a series of waves, which strike successively against the plate, and if the plate is free to move, it will vibrate backwards and forwards under the influence of these waves.

Sound is always the result of vibration, but not all vibration will produce sound. The motion of a swing to and fro is vibration, but it does not produce sound; a wire may be stretched between two points so loosely that, when struck or snapped, it will vibrate back and forth without producing sound, because in both cases the vibrations are too slow to produce the

COPYRIGHTED BY INTERNATIONAL TEXTBOOK COMPANY ALL RIGHTS RESERVED

necessary sensation upon the ear. If, however, the wire is drawn tighter, a condition will be reached where its vibration will produce a low musical tone, as is the case with the bass strings of a piano. The tighter the string is drawn the more rapid the vibrations and the higher the sound will become; and the harder the blow causing the vibration the louder will be the sounds. Also, strings made of different materials cause different sounds when vibrating; likewise, an organ pipe causes a different sound than a violin string, though both sounds may be equally high and equally loud.

3. The **pitch** of a sound is its degree of highness or lowness, and is dependent on the rate of vibration producing the sound. The strings of a piano are of different lengths and sizes and are adjusted with different degrees of tension so as to cause different rates of vibration resulting in different pitches of sound. *The higher the rate of vibration, the higher is the pitch of the sound.*

4. The **loudness** of a sound depends on the amplitude, or extent, of the vibrations causing it. *The greater the amplitude of vibration the louder is the sound*, as is illustrated by striking a piano key blows of different intensities.

5. The **quality**, or *timbre*, of a sound is the property by which different sounds are distinguished, even though they may have the same pitch and loudness. Thus, the sound of a flute is easily distinguished from the sound of a violin playing in the same pitch and with the same loudness; the voices of different persons can be distinguished from one another, without regard to pitch or loudness. This distinguishing quality of sounds depends on the *wave form* of the vibrating body.

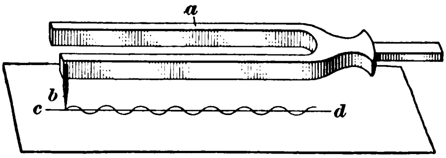


FIG. 1

A wave form may be illustrated by the experiment shown in Fig. 1, in which an ordinary tuning fork *a* has attached to one prong a pencil point *b*. If the fork is at rest and a sheet of paper is drawn under the pencil point, a straight line *c d* will be traced on the paper. If, however, the fork is thrown into vibration and the paper drawn under the pencil point in the same direction as before, a wavy line will result. This wavy line gives a conception of the wave form produced by the vibration of a tuning fork. The fork, however, does not vibrate in a wavy line. It merely moves back and forth, and this movement, combined with the movement of the paper in a direction at right angles to the direction of vibration, causes the pencil to trace the wavy line. Any other point on the vibrating body would trace a similar line under the same conditions.

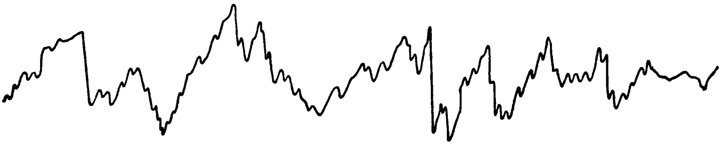


FIG. 2

6. If a pencil point could be attached to a particle of air, the point would trace a straight line on a sheet of paper drawn under it when the particle is at rest and some sort of a wavy line when the particle is vibrating. The shape of the wavy line would depend on the nature of the vibration.

A tuning fork produces a very simple wave form, as shown by the simple form of the wavy line which it drew in the experiment of Fig. 1. A string of a piano would draw a somewhat more complex wave form, because the string vibrates as a whole and also separate sets of vibrations of higher frequency are set up in its various parts.

Perhaps the most complex set of vibrations in the whole realm of sound are those of the human voice in speaking. It is probable that the sound waves set up in air by the voice would, if recorded on a strip of paper, look more like Fig. 2 than the simple wavy line of the tuning-fork experiment.

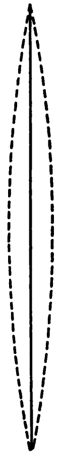


FIG. 3

7. A **vibrating diaphragm,** indicated in Fig. 3, shows more clearly the nature of the propagation of sound waves in air. This diaphragm is supposed to be of some thin elastic substance, such as sheet iron, and to be firmly supported at its edges. It is supposed, moreover, that it is maintained by some means in a constant rapid vibration to and fro between the limits indicated by the curved dotted lines.

As it moves to the right, there is produced a condensation of the atmosphere immediately in front of it at *a*, Fig. 4, and a rarefaction immediately in the rear of it at *b*. The condensation is communicated to the particles of air beyond, causing a wave of condensation to travel through the air, gradually diminishing in intensity until it is finally lost. When the diaphragm moves back to the left it causes a rarefaction near it, so that alternate waves of rarefaction and condensation follow one another in both directions as long as the diaphragm continues to vibrate.

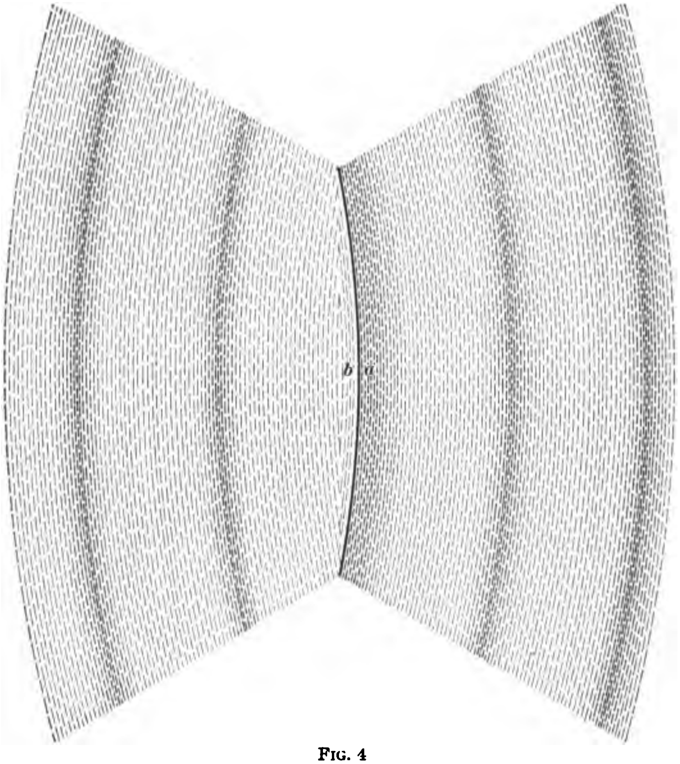


Fig. 4

While the wave travels outwards from the diaphragm, the particles of air through which the wave is propagated move only to and fro in a comparatively limited path. A similar action takes place when a pebble is dropped into a pond of still water. Waves are set up that proceed in the form of circles, of which the point where the pebble entered the water is the center. The wave undoubtedly travels over the surface of the water; but by observing small chips floating on the water, it will be seen that they move only up and down when acted on by the wave. In the case of sound waves, the to-and-fro motion of the particles of air is in the direction of vibration of the body causing the wave; in the case of ripples on the water, the to-and-fro motion of the particles of water is at right angles to the direction in which the wave moves.

REPRODUCTION OF SOUND

8. If two bodies can be made to vibrate exactly alike at a rate that will produce sound, the sounds will be exactly alike. This statement is true of all vibrating bodies and is the underlying law of telephony. The whole problem in the transmission of speech from one point to another, or, more properly, in the reproduction of speech at a distant point, is to cause a vibrating body at the distant point to imitate as nearly as possible all of the vibrations of the body producing the original sound.

In telephony, the body that reproduces the sound vibrations is in the form of a diaphragm, such as that of Figs. 3 and 4. The reason for using vibrating diaphragms instead of vibrating strings like those of a piano is that strings have a decided tendency to vibrate in their own predetermined way and thus to emit only one kind of sound. Small diaphragms, on the other hand, do not possess this characteristic to such a degree, for, as is well known, the small diaphragm of the phonograph has the power to vibrate throughout a wide range of rates and, therefore, to produce sounds ranging from those corresponding to the low notes of an organ to the high tones of a piccolo.

9. The action of a phonograph is purely mechanical. The recorder diaphragm vibrates in accordance with the sounds produced by the musical instrument, speaker, or singer, and these vibrations are made to cut a corresponding series of waves on the surface of the record. When these sounds are to be reproduced, a needle or stylus, carried on the center of the reproducing diaphragm, rides these waves cut in the record, and thus causes its diaphragm to reproduce the vibrations of the diaphragm that originally made the record. The reproducer diaphragm is thus made to vibrate in the same manner as did the recorder diaphragm under the influence of the original sounds, and it thus gives forth a more or less faithful reproduction of those original sounds.

In the phonograph, the sounds making the record set up air waves that strike on the recorder diaphragm, causing it to vibrate. By purely mechanical means the reproducer diaphragm is later made to vibrate in the same manner, thus giving forth a reproduction of the original sounds. The reproduction can be made at any place and at any time after the record is completed.

10. The simplest form of telephone, called the *lover's telephone*, is also purely mechanical in action. It can be made as shown in Fig. 5. The only materials needed are two tin cans (old vegetable cans will do) with both ends removed, two pieces of parchment or heavy paper, two buttons, and a long piece of small, hard twine. The parchment or paper is stretched tightly over one end of each can, like a drum head, and the string is passed through the center of each of these heads and fastened to a button inside each head.

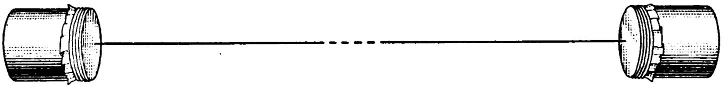


FIG. 5

When the cans are held so that the string is taut, sounds produced in one can cause its diaphragm to vibrate, these vibrations are transmitted by the string to the other diaphragm, and the sounds are thereby reproduced in the other can. Crude as it is, this apparatus transmits speech with sufficient exactness to enable two persons located several hundred yards apart to converse with each other in ordinary tones. As in a phonograph, the success of this device depends on its ability to make the diaphragm that reproduces the sound imitate the vibrations of the diaphragm that receives the original sounds. This is also true of the ordinary telephone, but its action is mainly electrical instead of mechanical.

RECEIVERS AND TRANSMITTERS

THEORY OF ACTION

11. Every complete electric telephone must include a receiver and a transmitter, each of which serves the purpose indicated by its name. The essential part of each is a diaphragm, and the diaphragm in the receiver is made to imitate very closely all the vibrations of the diaphragm in the transmitter of another telephone at a distance. Not only must the grosser vibrations be imitated, but also the more minute and delicate vibrations with their rapid changes in strength and frequency, so as to enable the receiver to give forth a sound that is a close reproduction of the original sound. In order to carry this into effect, the following steps in the process of transmission are necessary:

1. The transmitter diaphragm takes up the vibrations caused by the sound to be transmitted.
2. The vibrations in the transmitter cause corresponding electric currents in the line, and these currents are therefore of a wavy, or undulatory, nature. The current waves vary in strength, frequency, and direction in close imitation of the amplitude, frequency, and direction of the sound waves.
3. These *voice currents*, as they are called, affect the receiving instrument, causing its diaphragm to vibrate in accordance with the current variations and so imitate the movements of the transmitter diaphragm.
4. The receiver diaphragm vibrating in this way gives forth a close imitation of the original sound.

TELEPHONE RECEIVER

12. The action of a telephone receiver depends on the influence of varying current in an electromagnetic solenoid on a permanent magnet. This action can be explained by reference to Fig. 6, in which a thin iron diaphragm *P* is mounted close to, but not touching, one pole of the permanent magnet *N S*. A fine wire *c* is coiled around one end of the magnet and the terminals of this coil are connected directly in the circuit in which the instrument is to be used.

As the diaphragm is of iron and is rigidly mounted at its edges, being free to vibrate at its center, it is normally strained slightly toward the magnet by magnetic attraction. A current in the coil increases or decreases this attraction, according to whether the current increases or decreases the flux of the magnet. If the current is continuously in one direction but of varying strength, the flux varies with the current; if the current is alternating, the flux is alternately increased and decreased or perhaps reversed. In either case the diaphragm vibrates in unison with the current changes.

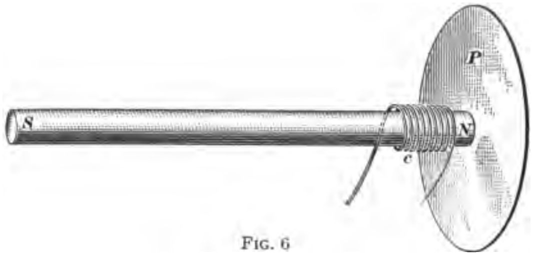


Fig. 6

The diaphragm of this simple device, like the diaphragm of the reproducer of the phonograph, is capable of emitting the most complex sounds; in fact, it is capable of imitating with fair accuracy all of the sounds of the human voice, of musical instruments, or of an entire orchestra. If the current causing the diaphragm to vibrate varies in accordance with the original sound waves, the vibrations of the receiver diaphragm will reproduce those sound waves, and therefore reproduce the sound.

TELEPHONE TRANSMITTERS

13. Magneto Transmitters.—The action of a magneto telephone transmitter depends on the fact that the number of lines of force in a magnetic circuit is changed by the movement of iron in that circuit and also on the principle of electromagnetic induction. In speaking close to an iron diaphragm arranged as shown in Fig. 6, the diaphragm is made to vibrate in accordance with the sound waves striking it. When the diaphragm swings toward the magnetic pole, the number of lines of force in the magnet is increased, and when the swing is away from the pole the number of lines of force is decreased. The varying flux through the magnet coil induces electromotive force in the coil; and if this coil forms part of a circuit, varying currents will be set up in the circuit, the current variations being in exact accordance with the sound waves striking the diaphragm.

14. This very simple device is therefore capable of producing current waves, or *voice currents*, that correspond very closely with the sound waves affecting the transmitter diaphragm. Two such instruments connected in one circuit, as shown in Fig. 7, represent the talking apparatus of the telephone invented by Bell. When the soft-iron diaphragm P is spoken against, it takes up the vibrations of the sound waves and thus causes changes in the strength of the magnetic field in which the coil S lies. These changes produce in the circuit currents that vary in direction, strength, and frequency of alternation in unison with the movements of the diaphragm; that is, these voice currents have the various characteristics corresponding to the relative loudness and pitch and quality of the sound that caused the diaphragm to vibrate. Though feeble, the voice currents alternately strengthen and weaken

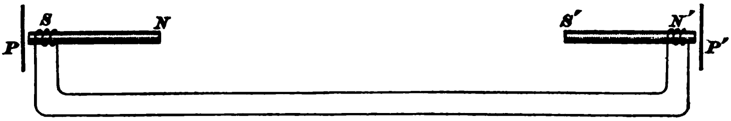


FIG. 7

the permanent magnet $N' S'$ at the other instrument and cause it to exert a varying pull on the diaphragm P'. This diaphragm therefore vibrates in unison with the changes in current and reproduces the sounds which actuated the diaphragm P. The action described as taking place in the instrument spoken to is that of a transmitter, and that in the instrument which repeats the sound is that of a receiver.

No battery is used with the magneto transmitter, because it generates its own current. It receives energy from the sound waves striking against its diaphragm and converts this energy into electricity. The magneto transmitter will transmit speech over short distances with a clearness greater than that of any other transmitter, but as it is limited to short distances, other transmitters are in general use.

15. Variable-Resistance Transmitters.—All commercial telephone transmitters are of the variable-resistance type; that is, movements of the transmitter diaphragm vary the resistance of a circuit in which direct-current electricity is flowing. The circuit must therefore contain a battery, which may or may not be located near the transmitter; if located near the transmitter and individual to it the system is called a **local-battery system.** If one larger battery is used to supply current for several telephones, **common-battery system** is the name given. In either case each transmitter acts as a valve, or throttle, in its circuit, controlling, or varying, the battery current in the circuit.

16. A variable-resistance transmitter is indicated in Fig. 8. A diaphragm *a* supported in a stationary ring *b* carries a carbon button *c* against which another carbon button *d*, mounted on a spring *e*, is lightly pressed. The two carbon buttons form part of an electric circuit, which also includes a battery *B* and a telephone receiver *R*. The pressure between the buttons is light, so that small variations in the pressure cause large variations in the resistance of the contact. Carbon is the best material for the buttons.

Sound waves striking against the diaphragm cause it to vibrate; these vibrations vary the resistance of the loose contact, the line current is varied accordingly, and the diaphragm of the receiver is thus made to vibrate in unison with the transmitter diaphragm.

17. Transmitters of the type just described are called **loose-contact transmitters**; they are also called **microphones** because of their ability to magnify minute sounds and make them audible. The buttons *c* and *d* forming the loose contact are the **electrodes**; the electrode nearest the diaphragm is called the *front electrode*, and the other is the *rear electrode*.

18. The most common form of variable-resistance transmitter is the **granular-carbon transmitter,** in which vibrations of the diaphragm increase and decrease the pressure on a chamber of carbon particles, thus varying the resistance of a multitude of loose contacts. Fig. 9 shows the principle. To the back of the diaphragm *a* is attached a carbon disk *b* which forms the front electrode. This electrode rests loosely against granulated carbon, back of which is another carbon disk *c*, forming the rear electrode, which is mounted on a rigid support *d*. The granulated carbon resembles ordinary gunpowder, and it is held in place between the two electrodes by a ring *e* of felt or some other material that will not interfere with free vibration of the front electrode nor form a conductor between the electrodes.

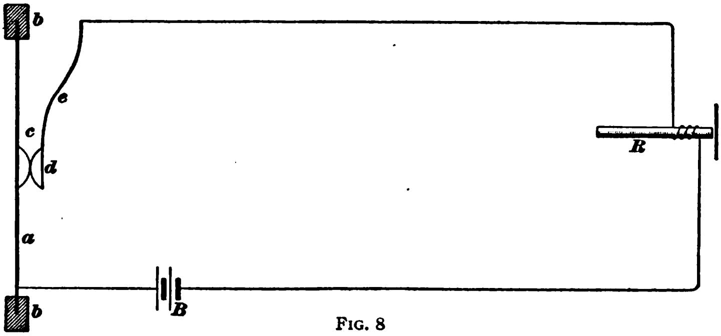


FIG. 8

The two electrodes and the carbon particles form parts of the circuit through the battery and the distant receiver. A large number of loose contacts exist between the front electrode and the granules, between the rear electrode and the granules, and also among the granules themselves. Sound waves striking the diaphragm cause it to vibrate and vary the pressure at the loose contacts, thus varying both the resistance of the circuit and the battery current in the circuit. These variations in current conform in frequency to the frequency of the sound waves, and in magnitude to the magnitude of the sound waves. The receiver at the distant end is therefore affected so that its diaphragm in exactly the same way vibrates in unison with the transmitter diaphragm, thus reproducing the sound.

19. Transmitter Connections.—The changes in the line current caused by a variable-resistance transmitter depend on the variations of the total resistance in the circuit. If the line resistance is large compared with the variable resistance, vibrations of the diaphragm will cause small variations of the total resistance and, consequently, small variations in the line current. Variable-resistance transmitters connected directly in the circuit, as shown in Figs. 8 and 9, therefore cause very small current changes in a long, high-resistance line.

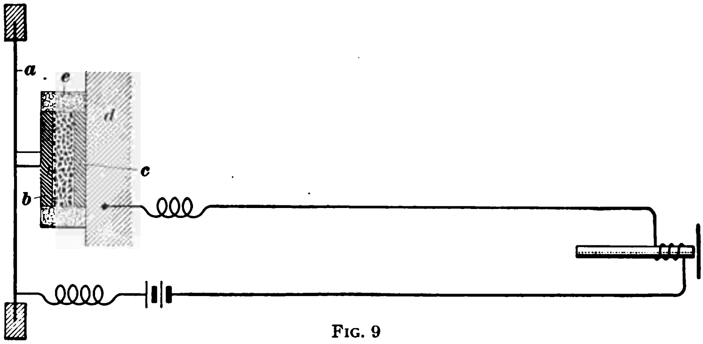


FIG. 9

20. By the use of an induction coil, however, the circuits can be arranged so that the transmitter is in series with only a comparatively short circuit that includes the primary winding of the coil, as indicated in Fig. 10. Here the transmitter *T*, the battery *B*, the induction coil *P S*, and the receiver *R* are represented by conventional symbols that will be much used throughout these pages. The two zigzag lines *P* and *S* represent, respectively, the primary and secondary windings of the coil. The secondary winding is in series with the receiver at the distant end of the line. With this arrangement the resistance of the circuit including the transmitter can be made very much lower than in the arrangement shown in Fig. 9, because the high resistance of the line wire indicated in this illustration is replaced by the low resistance of the primary coil in Fig. 10. A battery of a given voltage can therefore produce a larger current in this low resistance than in the high-resistance line circuit, and the transmitter can make greater changes in this current than if it had to vary the resistance of the entire line circuit.

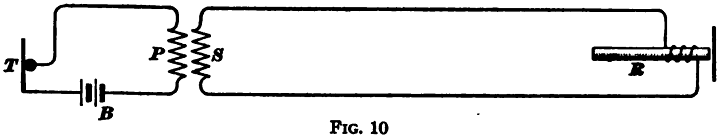


FIG. 10

21. Sound waves striking the transmitter, Fig. 10, make the diaphragm vibrate, thus varying the current in the local circuit. These variations in the primary current cause corresponding alternations in the secondary current, which is the line current that affects the receiver. In this case the primary current is fluctuating; that is, it is always in the same direction but of varying strength. The secondary current is alternating, or in constantly reversing direction; that is, it is in one direction when the number of lines of force is increasing and in the other when this number is decreasing, even though the direction of the lines of force remains unchanged.

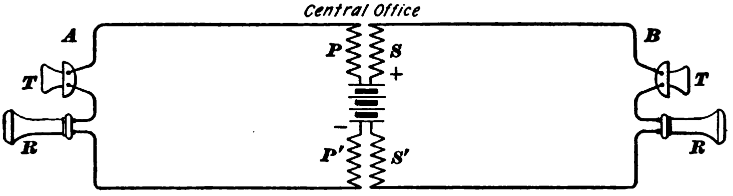


FIG. 11

22. The use of induction coils in a common-battery system is illustrated in Fig. 11. The primary, or transmitter, circuit here extends from the telephone to the common battery in the central office, where it passes through the primary winding of the induction coil. The transmitters T and the receivers R at two stations A and B are represented by common symbols, and are shown connected for conversation. The two line wires of station A are connected with the poles of the central-office battery through the windings P and P', respectively. Similarly, the two line wires of station B are connected to the same battery through the coils S and S'. These coils P, P', S, and S' are really all wound on the same core, but for simplicity the coils P and S may be considered the primary and secondary windings of one induction coil, P' and S' being those of another.

Steady direct-current electricity from the positive pole of the battery divides between the two coils P and S and follows each of the upper wires of the diagram to stations A and B, through the transmitters and receivers of those stations, thence back over the lower line wires, through the coils P' and S', respectively, where the two currents unite at the negative pole of the battery. In this way each of the transmitters is supplied with current for talking purposes.

23. The speaker at station A, Fig. 11, causes his transmitter to vary the resistance of the line circuit from A to the central office, and the resulting variations in the previously steady current in this line induce corresponding currents in the secondaries S and S' of these coils. These induced currents in the line to station B are superimposed on the steady continuous battery current in the same line, so that the current in the receiver at station B pulsates, or fluctuates, to correspond with the sound waves striking the transmitter diaphragm at station A. The receiver at B therefore reproduces approximately the same sound waves, and hence the same sounds, as enter the transmitter at A.

When the speaker is at station B and the listener at station A the functions of the windings of the induction coil are interchanged; the windings marked $S\,S'$ become primaries and the windings marked $P\ P'$ become secondaries. As a matter of fact, the coils $P P'$ and $S S'$ have the same number of turns. They are 1-to-1 coils and therefore do not serve to change the voltage and current. Their use is similar to that of the induction coil in Fig. 10, in that they enable each transmitter to work in a circuit of lower resistance than that of the combined turns. These coils also have other functions, which are explained later.

ELECTRIC SIGNALING

MAGNETO GENERATORS

24. Signals between telephones are essential in addition to facilities for transmitting speech. Such signals were formerly transmitted almost entirely by means of *magneto generators* and *polarized bells*, or *ringers*, and these devices are still much used. At the central offices, however, visual signals operated by electromagnets have replaced ringers, and electricity from the common battery is much used for signaling instead of that from a magneto.

25. In a **magneto generator,** often called a *magneto*, coiled conductors are rotated in the field of permanent magnets so that the number of lines of force enclosed by the coils is rapidly varied, thereby inducing electromotive force in the conductor. The intensity of the electromotive force thus set up depends on the rate at which the number of enclosed lines of force is varied. The coiled conductor and the core on which it is wound form the **armature** of the magneto.

26. Fig. 12 will assist in explaining the theory of a magneto generator. A coil a is indicated as capable of being rotated about an axis x in the field of three permanent horseshoe magnets $N\,S$. The dotted lines b indicate another position of the same coil as it rotates in the direction of the curved arrow. The lines of force of the magnetic field are indicated by horizontal broken lines with arrowheads to show their direction from north to south poles, according to the usual conception.

In its horizontal position the loop lies in a plane parallel with the direction of the lines of force and encloses none of them. In its vertical position the loop is at right angles to the direction of the lines of force and encloses practically all of them. The number of lines of force through the loop, therefore, varies between zero and a maximum for every quarter of a turn made by the loop.

While the loop is rotating at uniform speed the rate of change in the number of enclosed lines of force is least while passing the vertical position and greatest while passing the horizontal position. Therefore, the induced electromotive force is least while the coil is passing the vertical position and greatest while it is passing the horizontal position; that is, the induced electromotive force varies from zero to a maximum or vice versa for every quarter turn.

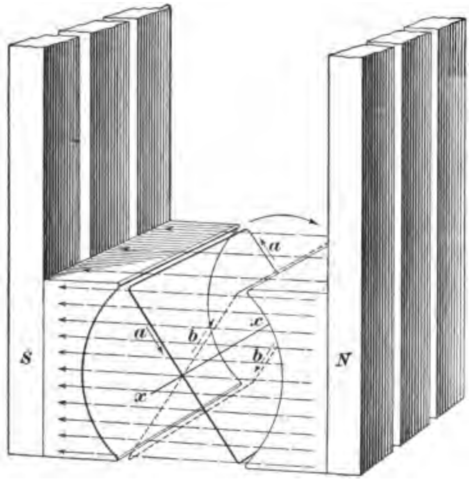


FIG. 12

27. The direction of the induced electromotive force in the coil depends on both the direction of the lines of force through the coil and on whether their number is increasing or decreasing. Every time the coil passes a vertical position, that is, a position where it encloses the maximum number of lines of force, the direction of the induced electromotive force reverses, because the number of enclosed lines of force then begins to decrease and their direction through the coil does not change. As the coil continues to rotate, the induced electromotive force remains in the same direction until the next vertical position is reached. It does not reverse at the horizontal positions, that is, where it encloses no lines of force, because at this point both conditions affecting the direction of induced electromotive force change simultaneously; the coil turns so that the lines of force pass through it in the reverse direction, and the number of enclosed lines of force begins to increase.

28. The rise and fall in the value of the induced electromotive force may be represented by a curve as in Fig. 13. Let *A* represent zero electromotive force induced when the coil is passing through a vertical position. The force then increases in one direction to its maximum value, represented by the point *B*, induced when the coil is passing through its next horizontal position. The force then decreases to zero, at *C*, when the coil reaches its next vertical position. Here the direction of the force in the coil reverses and then passes through the same series of values in the reversed direction, reaching a maximum value at *D* when the coil is again horizontal and returning to zero at *E* when the coil has completed one revolution. The whole series of values through which the induced electromotive force passes while the coil is rotated once is called a **cycle**. These cycles are repeated indefinitely as the coil continues to rotate. The current set up by such an alternating electromotive force is alternating and has corresponding cycles of values.

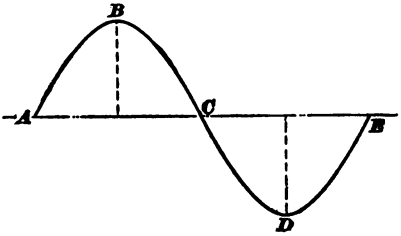


FIG. 13

29. Instead of having a single turn of wire, as in the loop shown in Fig. 12, a coil, consisting of a great number of turns, is used in practice, so that the electromotive force generated in each turn may be added to that of all the others. Furthermore, in order that the greatest number of lines of force may flow between the magnet poles and through the coil, the coil is wound on a core of soft iron adapted to fit closely between the curved iron polar extensions, or pole pieces, secured to the poles of the permanent magnets. Such a construction is shown diagrammatically in the left-hand portion of Fig. 14. In this, *A* represents the armature core of iron, adapted to rotate within the space formed by the iron pole pieces *P*, secured to the poles *N S* of the permanent magnet. In opposite sides of the armature core are longitudinal grooves in which the coil of insulated wire is wound. This coil entirely fills the groove, although for the sake of clearness only four turns are represented.

POLARIZED BELLS

30. The polarized bell, or *ringer*, shown diagrammatically in the right-hand part of Fig. 14, is a device that was primarily designed to respond to the alternating current produced by a magneto generator. Two soft-iron cores *e* and *f* are connected by a yoke piece *y* of similar material. Around these cores are wrapped, in opposite directions as shown, coils of insulated wire, these coils with their cores and yoke forming an ordinary double-coil electromagnet. An armature *a*, also of soft iron, is pivoted at its center so that its ends may be influenced by changes in the magnetism of the cores. The arm of a hammer located between the bells is rigidly attached to the armature and vibrates with it.

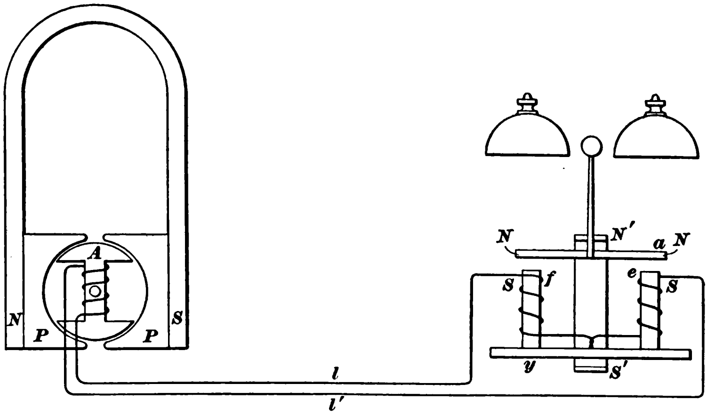


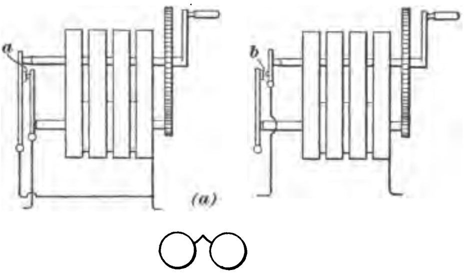
FIG. 14

A permanent magnet *N' S'* is so placed as to influence magnetically the cores *e* and *f* and the armature *a*. The magnetic circuit is through the armature *a*, the air gaps between the ends of the armature and the cores, the cores themselves, the yoke *y*, and the magnet. Both ends of the armature *a* are therefore north poles, and the adjacent ends of the cores are south poles.

Since the two magnet coils are wound in opposite directions, a current through them affects the cores *e* and *f* oppositely; that is, if the current is of such a direction as to make the upper end of the one core a north pole, it will tend to make the upper end of the other core a south pole. The south polarity of one core is thus strengthened, while the polarity of the other core, which is normally south because of the influence of the permanent magnet, is weakened and perhaps reversed. The end of the armature near the stronger south pole is attracted and the hammer strikes one of the bells. When the current reverses the other core becomes the stronger south pole and the hammer strikes the other bell. As the current set up in the magneto generator alternates in direction, it causes the armature of the bell to vibrate, and the hammer strikes the bells alternately.

CONNECTIONS FOR SIGNALING

31. A telephone line that connects only two distant telephones without extending to a central office may be called an *isolated line*, and a line connecting several telephones, a *party line*. Magneto generators for transmitting signals over isolated lines may be of the *series type* or of the *bridging type*. The latter is more generally used. In connection diagrams for telephones, generators and bells are represented by symbols, as shown in Fig. 15; in (*a*) two types of magneto generators are represented and in (*b*) a polarized bell is represented.



(*a*)

(*b*)

FIG. 15

SERIES MAGNETOS

32. Series magnetos are arranged for connection directly in the line in series with other magnetos and the ringers, as indicated in Fig. 16. Here are shown the connections for an isolated line having two stations *A* and *B* each with a magneto and a polarized bell. When either of the magnetos is operated, a current is set up in the whole line, ringing all the bells. In order to avoid the necessity of establishing this current in the armatures of magnetos not in use, each magneto is provided with a shunt, or path of low resistance, through which electricity for ringing passes around the idle magneto. This shunt is opened by means of a switch, as indicated at *k*, which normally maintains a closed circuit between the generator terminals. When the generator is operated its switch must be opened, as otherwise the electricity will simply follow the short circuit and not pass over the line.

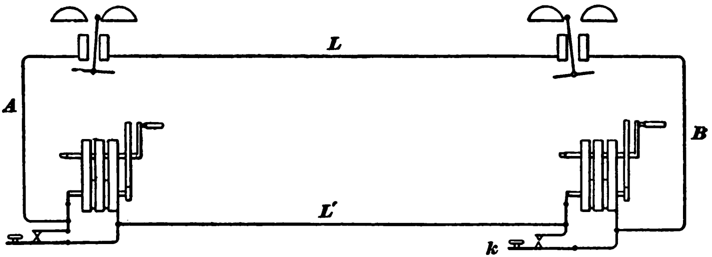


FIG. 16

33. In practice the switch is made part of the generator, so that the switch opens automatically at the point *a*, Fig. 15 (*a*), when the generator is operated. The name *automatic shunt* is applied to this feature, which keeps all the series magneto generators, except the one in use, out of circuit.

BRIDGING MAGNETOS

34. Bridging magneto generators are arranged for connection in parallel paths; that is, these generators are shunted, or bridged, across the circuit instead of being connected in series in it. Such an arrangement for permitting signaling between two stations *A* and *B* on an isolated line is indicated in Fig. 17. Instead of being provided with automatic shunts as in the series arrangement, the magnetos are placed in normally open circuits, a switch *k* being provided for closing the circuit when the generator is used. In practice, this switch is a circuit-closing device, or *generator cut-in*, as shown at *b*, Fig. 15 (*a*), which automatically completes the circuit by the mere act of turning the generator crank. When a generator is operated, electricity flows through it and through the ringers that are bridged across the circuit but not through other generators bridged across the line, because the cut-in switches of the other generators are open.

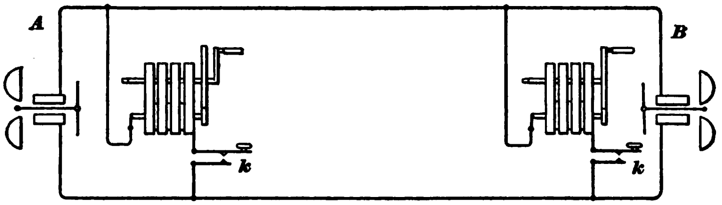


FIG. 17

35. In party-line connections not only the magnetos but also the ringers are nearly always bridged across the circuit. With series connections, the impedance of the ringer magnet coils would be too high for the voice currents when several such instruments are used in the same circuit. A typical party-line arrangement with four bridged instruments is shown in Fig. 18. As many as ten instruments may be so placed on a line with good results, and a much greater number has been

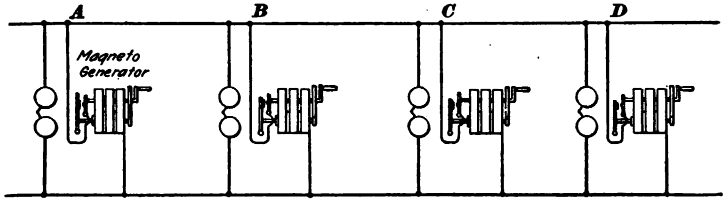


FIG. 18

used with moderate success. If the generator at station *A* is operated, its generator cut-in closes its circuit and electricity passes over the line and through all of the ringers in multiple, thus causing them all to sound in unison. It will not pass through the generator armatures of the other stations because they are all in normally open-bridge paths, their cut-in switches being open.

HOOK SWITCH

36. The hook switch is a device by means of which a telephone user automatically makes necessary changes in line connections, merely by lifting his receiver from its hook or replacing it thereon. The talking and signaling apparatus are never in use at the same time, but both are absolutely essential to the successful working of a complete telephone instrument. The hook switch affords a means by which the two sets of apparatus are switched alternately into and out of the line circuit without mental effort on the part of the telephone user. When the receiver is on the hook the ringer is in circuit ready to sound incoming calls. The act of raising the receiver from the hook disconnects the ringer and connects the talking apparatus in circuit; the act of replacing the receiver on its hook disconnects the talking circuit and reconnects the ringing circuit.

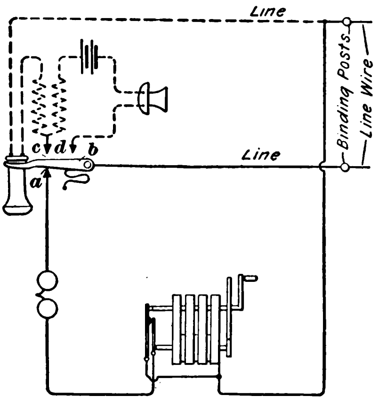


FIG. 19

37. The operation of a hook switch may be understood by the aid of Figs. 19 and 20, which show the connections of a series magneto telephone instrument. Fig. 19 shows the circuits when the receiver is on the hook, and Fig. 20 when the receiver is off the hook. Closed circuits in both cases are indicated by full lines and open circuits by dotted lines.

When the receiver is on the hook, as in Fig. 19, a circuit between the line wires is complete through the magneto, the ringer, contact *a*, and the metal hook-switch lever *b*. The talking circuit is now open at the contacts *c d*. When the receiver is off the hook, as in Fig. 20, the lever is forced up by the spring against contacts *c d*, and the contact at *a* with the ringing circuit is opened. A circuit between the line wires can now be traced for incoming voice currents through the receiver, the secondary *S* of the induction coil, contact *c*, and lever arm *b*. Also a circuit is closed through the local battery, the primary *P* of the induction coil, contact *c*, lever arm *b*, contact *d*, and the transmitter. Speaking in the transmitter varies the resistance of this local circuit and thus varies the current in it. The varying current in the primary causes corresponding variations in the secondary current, and as the secondary is now in series with the line, voice currents are established in the line. These voice currents affect the distant receiver when it is off the hook.

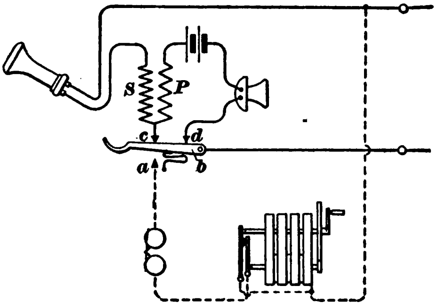


FIG. 20

38. In all telephones of the local-battery type, the function of the hook switch in holding the local circuit closed only while the instrument is in use and open at all other times is a very important one. When the hook switch is down and the local circuit is open, no battery current is being wasted. The flow from the battery can occur only while the hook switch is up, and the use of current is thus confined practically to the time when the instrument is actually in use. The functions of the hook switch in common-battery telephones is usually somewhat simpler than those just described, one reason being that in those telephones there is no local-battery circuit to be alternately opened and closed.

INDUCTIVE DISTURBANCES

39. Inductive disturbances in a telephone circuit are caused by alternating or varying current in conductors that are near and parallel to the conductors of the circuit. These disturbances are manifested as disagreeable humming noises in the telephone receivers and in some cases telephone conversation carried on over one circuit can actually be heard in receivers connected with a neighboring circuit. Inductive disturbances are caused by electromagnetic and also by electrostatic induction.

40. Electromagnetic induction, or, more accurately, mutual induction, causes the setting up of electromotive force in a conductor lying parallel and close to another in which current varies or alternates. In Fig. 21, line *a b* represents a wire carrying alternating or varying current and *c d* represents a grounded telephone circuit through two receivers. The lines of force surrounding the wire *a b*, which is the disturbing wire, alternately expand and contract as the current alternates, and in so doing they cut across conductor *c d* and establish alternating current in it. The result of alternating current in the receivers is a humming noise, the loudness of which depends on the nearness of the disturbing wire and the strength of the current in it.

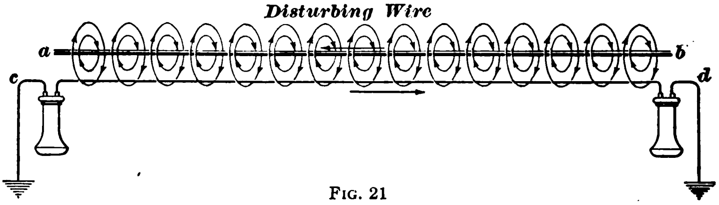


FIG. 21

41. Electrostatic induction depends on the principles of static electricity. Two wires lying near each other and parallel form a condenser, the air between them being the dielectric. When a charge of positive electricity flows into one, an equal charge of negative electricity is induced in the other. Therefore alternating electromotive force acting on one may induce alternating current in the other.

Fig. 22 represents a telephone wire lying near a disturbing wire, in which a current alternates or varies. The signs + and − indicate an instantaneous condition which changes with every change in the charge on the disturbing wire. A disturbing wire subjected to alternating electromotive force is thereby rapidly charged and discharged, and corresponding charges are induced in the telephone wire lying near it.

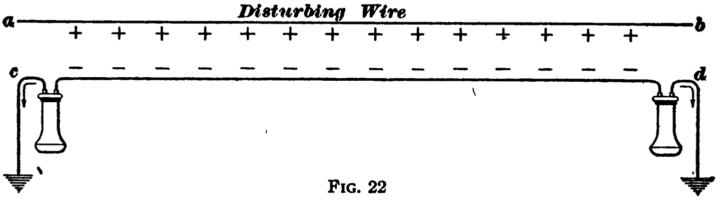


FIG. 22

42. The disturbing wire may be an electric light or power wire or it may be another telephone wire. Voice currents in one wire may act on an adjacent wire as just described. Induction may take place between two or more adjacent telephone lines to such a great extent that a conversation carried on over one line may be heard on the others, even though the lines are entirely insulated from each other. The **cross-talk** thus caused may produce much confusion when one or more subscribers are talking at the same time over grounded circuits.

43. In commercial telephony, cross-talk has been successfully overcome by the use of properly designed metallic circuits instead of grounded lines. If the two wires of a metallic circuit are arranged so that the electromotive force induced in either wire is exactly balanced by an equal and opposite electromotive force induced in the other, no cross-talk or other inductive disturbance will be developed. For example, if a

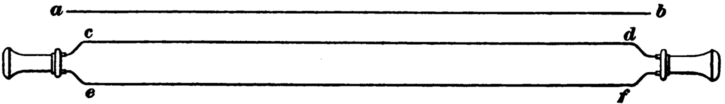


FIG. 23

disturbing wire *a b*, Fig. 23, is equally distant at all points from each of the two wires *c d* and *e f* of a metallic circuit, no inductive disturbance will arise in the circuit. If impossible to maintain the wire *a b* at equal distances from the telephone line wires, transposing the wires of the circuit, as at *g*, Fig. 24, helps to equalize the induced electromotive forces. Twisting the wires, as in Fig. 25, is the most nearly perfect form of transposition, and practically eliminates all objectionable inductive disturbance from other circuits. *Twisted pairs*, as they were called, must be used to prevent cross-talk when a large number of wires are bunched into a small space, as in telephone cables.

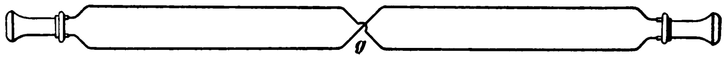


FIG. 24

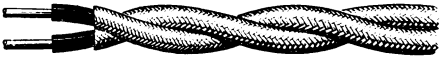


FIG. 25

THE TELEPHONE EXCHANGE

DEFINITION OF TERMS

44. A **telephone exchange** is a group of telephone lines with associated apparatus so arranged that the lines may be interconnected to give communication between any two telephone users in a community. The services of a telephone exchange may extend to the telephones of a small village with few lines or to those of a large city with many thousands of lines. Ideal telephone service enables any person anywhere to communicate with any other person wherever located, and telephone exchanges help in approaching this condition.

45. The patrons of the telephone service, that is, the persons who subscribe to the service of any telephone exchange, are called the **subscribers**, and the place in the subscriber's premises where his telephone is located is termed the **subscriber's station**, sometimes contracted to *substation*. The telephone apparatus at the subscriber's station is called the **subscriber's station equipment,** or the *substation equipment.* A single subscriber may have one or many stations.

The building containing the switchboard that serves a group of lines in an exchange is called the **central office**; the switchboard with its associated apparatus contained in the building is called the **central-office equipment.**

46. The telephone lines of an exchange are of three classes, *subscribers' lines*, *trunk lines*, and *long-distance*, or *toll*, *lines.*

From the switchboard in the central office the **subscribers' lines** radiate to all the subscribers' stations in the city. A line that serves only one substation is an **individual line,** or *private line;* a line that serves several substations is a **party line.**

In large cities, the exchange sometimes includes several central offices located in different parts of the city and interconnected by **trunk lines,** which are used to connect subscribers whose lines terminate in different offices. In some large offices different parts of the office are connected by *local trunks*, which are also for common use.

Long-distance lines, or *toll lines*, connect different exchanges and are so called because a special toll charge is made for their use. The subscription contract usually covers connection with any telephone served by a single exchange, but if connection is made with a telephone in another exchange a toll line must be used and an additional fee is charged.

MAGNETO EXCHANGES

47. Small exchanges, usually involving not more than two or three hundred lines, commonly employ magneto generators at the subscribers' stations to signal the central office. The device responsive to the current sent out by these generators is usually some form of electromagnetic drop, the operation of which may be understood by reference to Fig. 26. A shutter is held in a raised position by a latch that is attached to the armature of a magnet. When the magnet is energized by a current, the attraction of the armature will raise the latch and permit the shutter to fall, thus giving a visible rather than an audible signal to the operator.

Exchanges employing magneto generators at the subscribers' stations for calling and electromagnetic drops at the central office for indicating the calls are referred to as **magneto exchanges.**

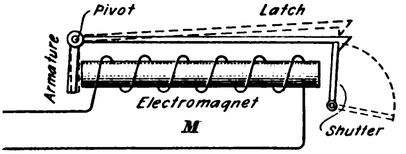


FIG. 26

The telephones in such exchanges are equipped with ordinary polarized bells, and in order to ring these bells the central office must have a source of ringing current. The operator has within her control switching devices that enable her to connect this source with the line to ring the subscriber's bell.

48. The operation of a magneto exchange may be understood by reference to Fig. 27, which shows the general arrangement of the switching apparatus that is manipulated by the operator at the central office. On the upper portion of the vertical face of the switchboard are mounted the shutters *s* of the line drops, these bearing the numbers of their corresponding lines. Immediately below each shutter is **a plug socket,** or *jack*, *j*, each of which is identified with the line corresponding to the drop above it, and has within it contacts in which the line conductors terminate.

On the horizontal shelf and near the switchboard are arranged a number of pairs of plugs *p* and *p'*, ten pairs being shown in this figure. The plugs nearest the vertical face of the switchboard are called *answering plugs;* those farthest from it are called *ringing plugs*. These plugs are adapted to fit into the jacks and are provided with metallic contacts which register with the contacts in the jack. One of these answering plugs is shown so inserted into jack No. 30 and its mate, the ringing plug, into jack No. 3. Each of the plugs is provided with a flexible cord *c*, which normally passes down through the plug shelf so as to be hidden from view. These cords are flexible enough to permit the plugs to be lifted and inserted into the jacks, as indicated in the illustration.

Each of these cords consists of two or more insulated flexible conductors, which terminate at one end in the contacts of a plug and are connected at the other end to the conductors of another cord and to the operator's set of apparatus. When the two plugs of a pair are inserted into jacks, as at jacks *30* and *3*, Fig. 27, the lines terminating in these jacks are interconnected by the cord circuit for conversation.

49. In front of the plugs on the horizontal shelf are shown a row of keys *k* termed *ringing* and *listening keys*. One of these keys is associated with each pair of plugs and cords, and each of the keys has two positions besides its *normal*, or *center*, *position*. When thrown one way, it is in its *listening position;* when thrown the other way, it is in its *ringing position*. By moving a key to the listening position, the operator connects her talking set across the corresponding pair of cords, and if the answering plug of this pair is at the time connected with

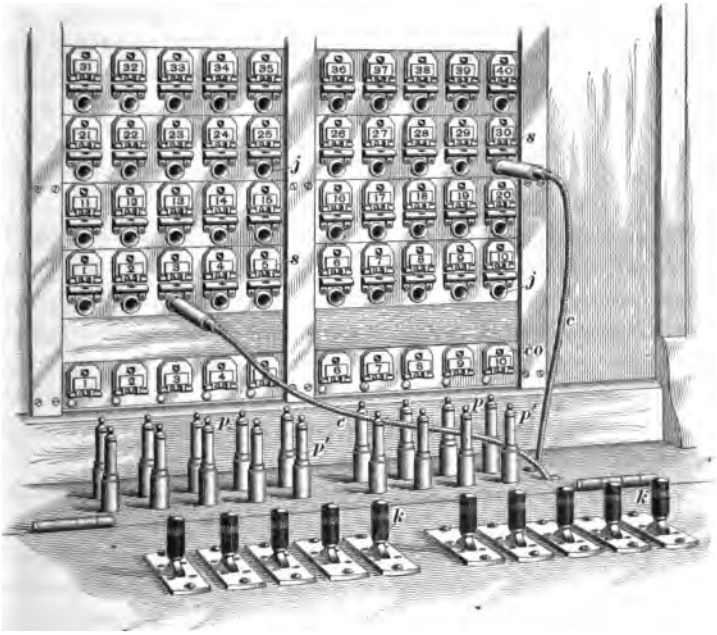


Fig. 27

a subscriber's line, as at jack *30*, Fig. 27, the operator is enabled to converse with the subscriber on that line. By moving the key to its ringing position, connection is made between the corresponding ringing plug and a ringing generator in the office. The generator produces current of the proper frequency and voltage to ring the polarized bells, and if this particular ringing plug is in a jack, as at jack *3*, the subscriber's bell on that line will ring.

The operator is provided with a telephone receiver and transmitter, the receiver being held to her ear by a head band and the transmitter either suspended from a stationary support or mounted on her chest, so as to be always in convenient position to receive her speech. This arrangement of the operator's receiver and transmitter permits her the free use of both hands. The operator's receiver and transmitter and the associated induction coil constitute the operator's talking set.

50. Associated with each pair of plugs is a clearing-out drop *c o*. These drops are mounted immediately above the plugs on the vertical face of the board and serve as signals by means of which the connected subscribers may signal to the operator that the conversation is finished.

The various steps in the operation of such a switchboard for the connection indicated by the plugs inserted in jacks *30* and *3* are as follows:

1. Subscriber No. 30, desiring a connection, turns his magneto-generator handle, causing drop *30* to fall.
2. The operator, seeing the signal, inserts the answering plug into the jack immediately below drop *30* and at the same time throws the key *k* corresponding to the plug into its listening position. The operator's set is now connected with the line and she is enabled to ascertain from the calling subscriber that he desires conversation with subscriber No. 3.
3. The operator inserts the ringing plug of the same pair into jack *3*, which is the jack of the called subscriber's line.
4. The operator throws the same key as before to its ringing position, thus connecting the ringing generator with the line of the called subscriber and ringing his bell; this act also

disconnects her telephone from the circuit. After ringing a short time the operator restores the key to its normal position.

5. When subscriber 3 responds to the call, the two subscribers converse over the combined circuit of their two lines and the connecting pair of plugs and cords.

6. When the conversation is finished the subscribers hang up their receivers and one, or both, of them is supposed to turn his magneto generator. This act sends ringing current over the line and operates the clearing-out drop associated with the pair of plugs and cords used in making the connection.

7. The operator takes down the connection by withdrawing the plugs from their jacks and allowing them to drop to their normal places on the plug shelf.

COMMON-BATTERY EXCHANGES

51. In common-battery exchanges, as already pointed out, the local batteries and the magneto generators at the subscribers' stations are dispensed with, all sources of current for both signaling and talking being located at the central office. The fundamental condition at all subscribers' stations in a common-battery exchange and one of the most important things to be remembered by telephone workmen, is as follows: *The line circuit is open to direct current when the receiver is on its hook and closed when the receiver is removed from its hook. There is no conducting path between the two sides of the line except when the instrument is in use.*

SIGNALING THE OPERATOR

52. The fact that direct current for energizing the transmitter is needed only when the receiver is off its hook enables the subscriber to signal the central office automatically when the receiver is raised, because the hook switch then closes the line circuit and electricity flows from the central-office battery to supply his transmitter. In the path of this current at the central office is a device that responds to this current and thus gives a signal to the operator. This signaling device may be in the form of a *visual target* or a *small electric lamp*, the latter being generally used except in very small exchanges.

53. A visual target signal may be explained by reference to Fig. 28. An electromagnet is provided with a pivoted armature to which is rigidly attached a rod carrying a vertical signal target. Normally this signal target is concealed behind a shield, but when the electromagnet is energized the attraction of the armature raises the target so as to bring it into view through the window or opening in the shield, as indicated by dotted lines.

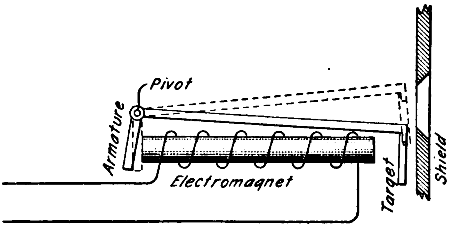


FIG. 28

The arrangement of such a signal in the circuit of the subscriber's line is shown in Fig. 29. The contact at *a* with the hook lever is open when the receiver is on the hook, and it closes automatically when the receiver is raised. When this contact is closed a circuit is complete from the central-office battery through the magnet coil of the signal, the subscriber's receiver and transmitter, the lever arm, and the battery. As soon, therefore, as the subscriber takes his receiver from its hook, the signal is automatically given to the operator at the central office and the subscriber's transmitter is energized. One advantage of this type of electromagnetic signal is that it automatically restores itself when the circuit is opened, the target simply falling back by gravity to its concealed position.

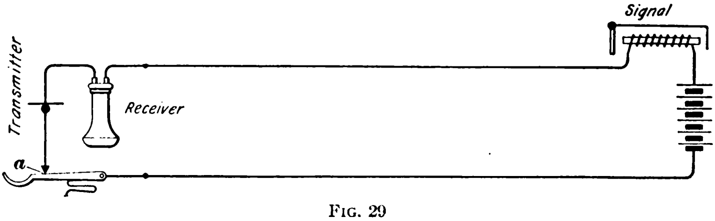


FIG. 29

54. Signal lamps for telephone switchboards are made very small so as to occupy little space on the boards. The lamp may be connected directly in the telephone line or in local circuits. Local-circuit connection is preferable and is most commonly used.

55. Direct-line connection is illustrated in Fig. 30. The lamp is in circuit with the subscriber's telephone and receives electricity when his receiver is off the hook. This is the simplest way of connecting signal lamps, but is not generally used, because not all subscribers' lines are of equal length and resistance. If the lamps were connected in the lines the current in some lamps would be too large and in others too small. Some lamps might therefore be burned out and others would scarcely glow.

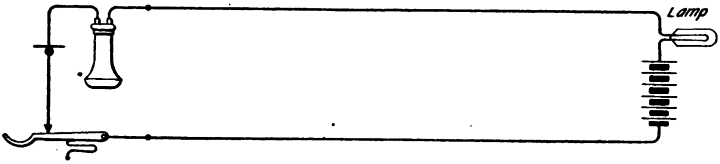


FIG. 30

56. Local-circuit connections are shown in Fig. 31. When the receiver at the subscriber's station is removed from its hook, an electromagnet in the line circuit closes a contact *a* in a relay circuit containing the signal lamp and places the lamp across the battery. The lamps can therefore be selected for full battery voltage and all lamps will receive the same current regardless of the lengths of the lines.

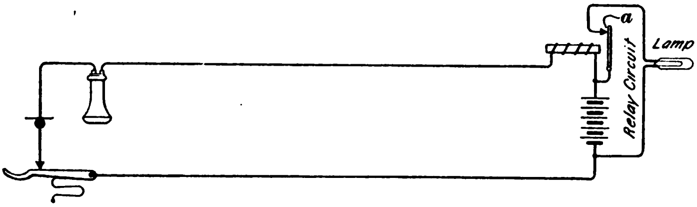


FIG. 31

SIGNALING THE SUBSCRIBER

57. Signals to the subscriber's station from the central office are received through a polarized bell and a condenser in series across the line circuit, as shown in Fig. 32. No conducting path then exists between the two sides of the line when the telephone is not in use, which is one of the fundamental conditions for such circuits. But while the condenser keeps the circuit open to direct current, it does not interfere with the flow of alternating-current electricity used for ringing. In order to signal the subscriber, the operator, by means not shown, connects the alternating-current generator at the central office across the line, and the current thus set up in the circuit through the bell causes it to sound.

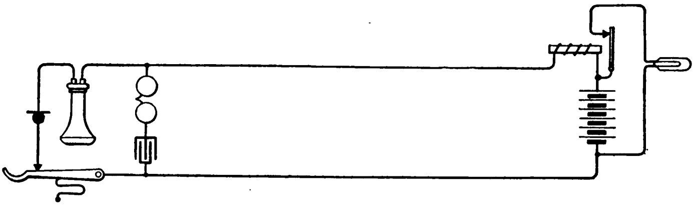


FIG. 32

58. A general idea of the operation of a small common-battery exchange can be obtained by referring to Fig. 33. Instead of drops the face of the board contains small lenses *l* behind which are signal lamps. Immediately above each lens is a jack *j*. One of the advantages of the incandescent lamp as a line signal is now apparent in the very much smaller space which a given number of signals and jacks can be made to occupy. As in the case of the magneto board, the plugs *p* and *p'* are arranged in pairs on the horizontal shelf. Immediately in front of the plugs are two rows of lamps *s* and *s'*, termed *supervisory signals*, and in front of these the ringing and listening keys *k*.

The supervisory lamp associated with each plug is placed under the control of a line as soon as its plug is connected with that line in much the same way that the line lamp is controlled before a connection is made with the line. There is a difference, however. Before a connection is made with the line, the line lamp lights when the subscriber removes his receiver from its hook. After a connection is made with the line by means

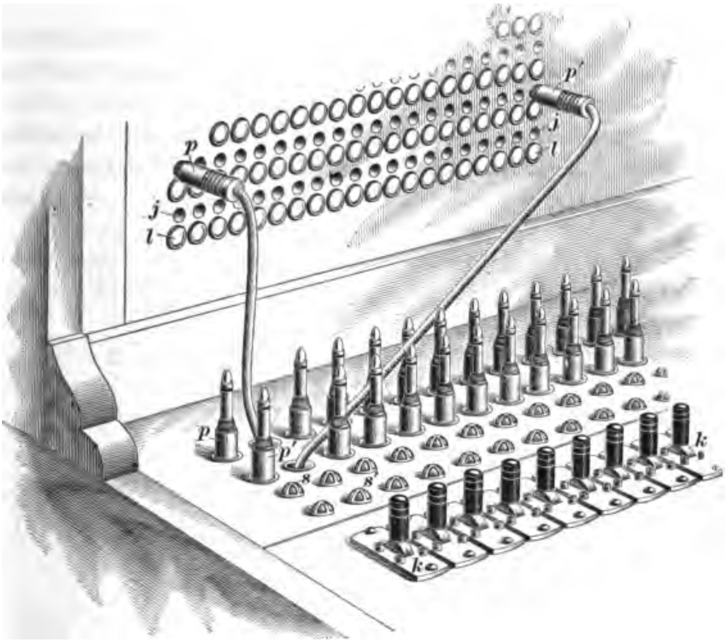


Fig. 33

of a plug and cord, the supervisory lamp associated with that plug and cord will glow only when the subscriber hangs up his receiver.

59. The various steps in the operation of such a switchboard are similar to those in the operation of a magneto switchboard, and are as follows:

1. A subscriber desiring a connection, removes his receiver from its hook. This causes the lighting of the line lamp immediately under his line jack.

2. The operator, seeing the signal, inserts one of the answering plugs into the jack immediately above the lamp, thus extinguishing the light. At the same time she throws the

key corresponding to the plug into its listening position. The operator's set is now connected with the line and she learns from the calling subscriber the number of the line to be called.

3. The operator inserts the calling plug of the same pair into the jack of the called line.

4. The operator throws the same key as before into its ringing position, thus connecting the ringing generator with the line of the called subscriber and ringing his bell.

5. When the operator plugs into the line of the called subscriber, the supervisory lamp corresponding to the ringing plug lights, and when the called subscriber responds, this light is extinguished, indicating his response to the operator.

6. When the conversation is finished the two subscribers hang up their receivers. As each one does so, the corresponding supervisory lamp lights.

7. The operator being thus informed that both receivers are replaced on their hooks, takes down the connection, restoring all parts to normal condition.

TELEPHONE PROTECTION

ELECTRICAL HAZARDS

60. In order to make telephones safe for their users and practically proof against injury to property, means of protection must be provided against the electrical hazards involved. These hazards arise chiefly from sources outside the telephone systems; that is, from foreign currents. Such currents have both a *heating effect* and a *chemical effect*, and protection against them is essential.

HEATING EFFECT OF ELECTRIC CURRENT

61. One of the most common examples of the heating effect of electric current is in the filaments of electric lamps, which are heated to such a high temperature that they glow brilliantly. Electric current in any conductor tends to heat it, the quantity of heat depending on the resistance of the conductor and on the square of the value of the current. For example, a given current in a 4-ohm conductor will develop four times as much heat as it would in a 1-ohm conductor; also in a given conductor a current of 6 amperes will develop four times as much heat as would a current of 3 amperes, because $6=2\times3$, and $2^2=4$.

Energy expended by a current in heating a conductor is usually considered as lost energy, because it serves no useful purpose; it is referred to as the I^2R loss, for the reason just explained, I representing current in amperes, and R, resistance in ohms.

62. The heating effect of current enters into the art of telephony mainly as a necessary evil. On the other hand, it is also made to achieve certain very useful results. The harmful effects arise first, from the loss of energy in the useless heating of wires, and, second, from the damage that may be done by overheated conductors. The energy loss in uselessly heating the wires and surrounding objects cannot be avoided, though it can be reduced by using larger wires and smaller currents. Overheated conductors may not only destroy their insulation and that of surrounding conductors, but they may cause loss of property by fires.

63. The hazards of overheated conductors in telephony arise principally from lightning discharges and from accidental contacts with the conductors of light and power circuits. The chief precautions must therefore be to guard against these conditions. Circuits must be provided for the easy and harmless escape of lightning discharges to ground and for the automatic opening of telephone circuits over which injurious foreign currents are reaching the apparatus.

64. The voltages actually employed in telephone circuits' although low, might cause damage to certain parts of the apparatus if those parts were subjected to the entire voltage. For example, the lamp of Fig. 30 is so proportioned that it will burn at normal voltage when connected in series with the resistance of the line and the subscriber's station apparatus.

Therefore it is normally subjected to but a fraction of the total battery voltage. If the line should become short-circuited close to the central office, the principal resistance of the line would be cut out and the lamp would receive practically the entire voltage of the battery and would probably be destroyed, because it is not made for such voltage. Again, many portions of telephone equipment are of such a nature as to carry safely the currents on which they are designed to operate for the short intervals involved in their use, and yet be injured should an even smaller current pass through them for a much longer time.

65. A **fuse** is a link of metal of lower carrying capacity and usually of lower melting point than the rest of the circuit of which the fuse is a part. When the current rises to a value that may injure any of the apparatus in the circuit, the fuse, if rightly proportioned, melts and opens the circuit. Thus, the heating effect of the current is made to safeguard the apparatus.

Fuses are usually composed of some alloy of lead. Zinc also is widely used. These metals melt at a reasonably low temperature and have a lower conductivity than copper. A small copper wire or a very small iron wire coated with copper is, however, sometimes used in fuses of small carrying capacity. The only objection to copper and iron for this purpose is that they melt at higher temperatures and are more likely to injure surrounding objects than is lead, which melts before a dangerous temperature is reached. Ordinarily, a fuse for telephone work is enclosed and protected by a fiber tube with conducting terminals, thus preventing the melted particles and gases from injuring near-by objects when the fuse is melted, or *blown*, as it is termed.

66. A **sneak-current arrester** is an arrangement whereby a small low-voltage current that might injure apparatus if allowed to continue indefinitely is made to heat a coil of wire in the same circuit enough to melt a small quantity of low-fusing solder. This solder serves to hold a spring in a strained position, so that when the solder melts, the spring moves to its normal position and by this movement opens the circuit or grounds it, or does whatever is necessary to afford the protection desired. Both fuses and sneak-current arresters are considered later in discussing the portions of telephone work to which they most nearly relate.

67. An **air-gap arrester,** or *open-space cut-out,* is a device that allows the escape of high-voltage currents to the ground. This arrester consists essentially of an air gap between two conductors, one of which is connected with the circuit and the other with the ground. If the potential of the circuit rises dangerously high, as in case of a lightning discharge or a cross with a light or power circuit, electricity will jump across the gap, forming a spark in so doing and giving rise to the name *spark gap.* The discharge then escapes harmlessly to the ground.

The usual form of spark gap consists of two plates of carbon separated by a very thin air space. The voltages employed in telephony are not high enough to cause electricity to jump this gap, thus keeping the telephone currents confined to the proper circuits. The air-gap arrester, in combination with the fuse, forms the usual protective apparatus at subscribers' stations. An air-gap arrester, in combination with the heat coil, is employed for protection at the central-office end of the line.

CHEMICAL EFFECT OF ELECTRIC CURRENT

68. Chemical action, which is so useful in voltaic cells, and which may be called *electrochemical action,* sometimes injures portions of telephone property. In a voltaic cell the plate from which the current enters the electrolyte is gradually consumed. If electricity were forced through the cell in the same direction from an external source this plate would be consumed more rapidly. The action by which metal is dissolved in a liquid, due to the action of electric current, is called **electrolysis.**

69. Telephone wires must frequently be placed underground, and when this is done a number of wires are usually bunched together and enclosed in a lead sheath for protection against moisture. The negative terminals of electric railway

generators are usually connected with the rails, and the electricity is expected to follow the rails from the cars back to the generators. Some of this electricity, however, leaves the rails and enters any good conductors leading back toward the power house. Stray currents therefore follow telephone cable sheaths in some places and leave them where paths of lower resistance can be found. The lead sheaths are usually abandoned by these currents in moist earth or in water lying in cable ducts. No damage occurs where the stray current enters the sheath, but where it passes from the sheath in the presence of moisture, damage is likely to occur by electrolysis, the sheath being gradually eaten away just as in the case of the zinc electrolyte in a primary cell.

SUBSCRIBERS' STATION EQUIPMENT

(PART 1)

SINGLE-STATION EQUIPMENT

CLASSIFICATION

1. Subscribers may be individuals, corporations, or firms, and each subscriber may have one or many telephones. By subscribers' station equipment is meant the telephone apparatus placed on the premises of subscribers. If this equipment consists of a single telephone, it is called a *single-station equipment*. A subscriber who contracts for a large number of sets attached to one or several lines is said to have a *multi-station equipment*. The telephones in such an equipment may be connected in a variety of ways to meet the special requirements of the installation.

Multi-station equipments range all the way from a group of two telephones so arranged that the subscriber may receive or transmit a central-office call from either instrument, to a group of several hundred telephones so arranged that any station may call or be called from any other station in the system, and all stations may receive and transmit calls to the central office. The latter case requires a switchboard on the subscriber's premises, so such a subscriber's equipment becomes a small exchange. For this reason it is known as a *private-branch-exchange system*. The switchboard in such a system is operated in the same manner as that in a regular exchange.

COPYRIGHTED BY INTERNATIONAL TEXTBOOK COMPANY. ALL RIGHTS RESERVED

COMPONENT PARTS OF TELEPHONE INSTRUMENTS

TRANSMITTERS

2. Two views of a complete magneto telephone are shown in Fig. 1. This figure is merely to give a general idea of the component parts of a telephone and of the way in which the parts are assembled. A magneto instrument is chosen for this illustration because it contains more kinds of apparatus than the simpler common-battery instrument, though the latter is more generally used.

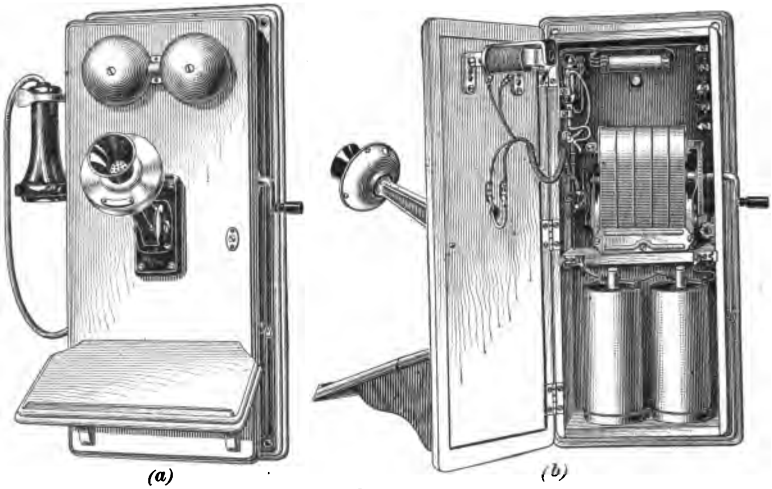

(a) (b)

Fig. 1

The type of transmitter most generally used by the Bell companies is known as the *White*, or *solid-back*, ***transmitter***. This employs granular carbon between two carbon-plate electrodes as the variable-resistance medium, the construction being as shown in the sectional view of Fig. 2 and the rear view of Fig. 3. The hard-rubber mouthpiece *a*, Fig. 2, is threaded to engage a screw thread on the internal ring of the front casting *b*, which fits into the outer rim of the shell *c*. The front and rear carbon disks, which form the electrodes, are shown

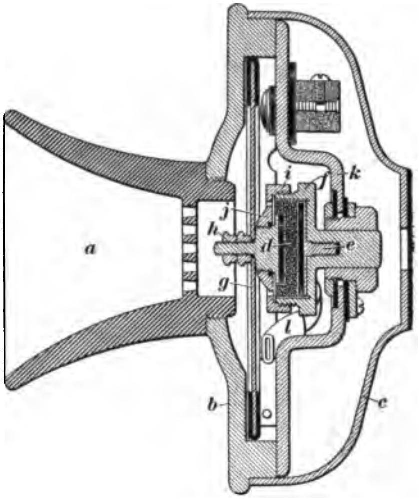


FIG. 2

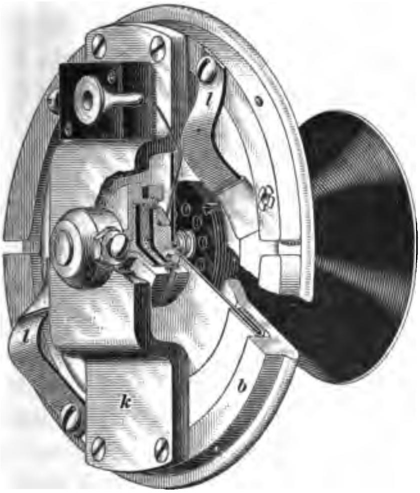


FIG. 3

in heavy black on either side of the granulated carbon *d*. The rear electrode is soldered to a brass disk having a small projecting shaft *e* that is screwed into the bottom, or rear, of the brass cup *f*. The front electrode is attached to a brass disk from which a threaded stud passes through the diaphragm *g* to permit of the front electrode being clamped rigidly to the diaphragm by means of the two small nuts *h*. The cup *f* containing the granular carbon is closed by a mica washer, which is clamped to the cup by a threaded ring *i* and to the front electrode plate by a threaded ring *j*. The only relative motion therefore possible between the two electrodes is that permitted by the flexing of this mica washer. The washer serves to close the carbon chamber, thus preventing the granular carbon from falling out and moisture from getting in, and at the same time provides the necessary play between the electrodes. The cup *f*, the electrodes, granular carbon, front electrode plate, mica washer, and clamping rings are assembled at the factory and form the variable-resistance part of the transmitter. This entire structure is fastened to the bridge *k*, Figs. 2 and 3, which is attached to the front piece *b*. The fact that the rear electrode is thus rigidly supported is responsible for the name *solid back*.

3. Transmitters, to reach their maximum efficiency, should not be too sensitive, and the degree of sensitiveness is dependent in a large measure on the flexibility of the diaphragm. Two springs *l*, Figs. 2 and 3, known as *damping springs*, bear on the rear face of the diaphragm at points between its outer edge and center. These springs are prevented from coming in direct contact with the diaphragm by insulating pads. By reducing the flexibility of the diaphragm, they eliminate, to a large extent, the confusion of sounds that would otherwise result from its free movement.

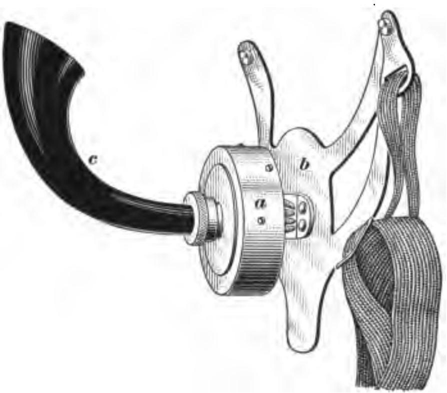


FIG. 4

4. In assembling the transmitter, the variable-resistance part is first loosely supported in the bridge. Then the clamping nuts *h*, Fig. 2, are tightened, thus rigidly securing the front electrode to the diaphragm. The diaphragm is gently tapped to make the rearwardly projecting stud on the cup *f* assume a natural position in the bridge so as to remove all initial strain from the mica washer, after which a clamping screw, Fig. 3, is tightened against the stud.

5. A modification of the transmitter described, and used by private-branch-exchange and central-office operators, is shown in Fig. 4. The transmitter proper, shown at *a*, is of the ordinary solid-back, granular-carbon type, and is fastened to a plate *b*, which in turn can be supported on the operator's chest by straps. It is provided with a long curved mouthpiece *c*, which projects to just in front of the operator's lips.

RECEIVERS

6. Fig. 5 is a cross-sectional view of a standard Bell receiver. A hard-rubber barrel *a* and ear piece *b* are threaded so as to screw together. The permanent magnet *c* fits inside of the barrel and has poles projecting close to the diaphragm *d*. On these poles are the magnet coils with terminals at screws *e* to which the ends of the receiver cord are fastened.

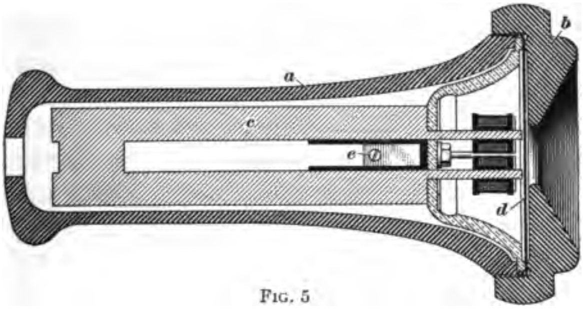
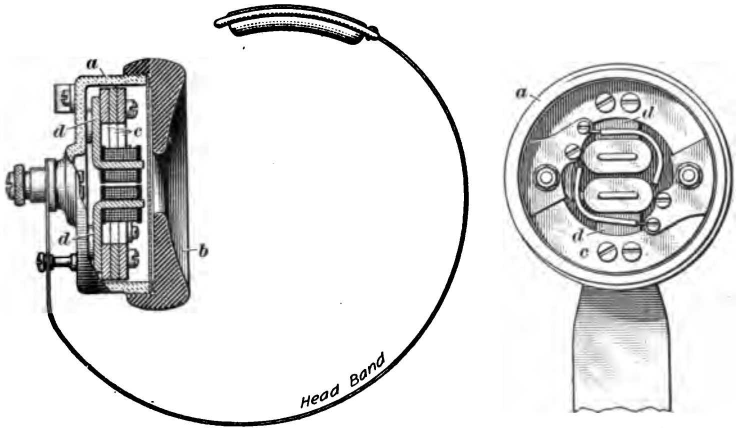


FIG. 5



(a) (b)

FIG. 6

7. The construction of a compact form of receiver, known as the *watch-case receiver*, is shown in Fig. 6. The view given in (*a*) shows a section and the view given in (*b*) shows the end with the ear piece and diaphragm removed. When equipped with a head-band, as shown, it forms the head receiver, as used by switchboard operators.

Although the principle of operation is the same as in the larger hand receiver, the construction is necessarily varied to decrease both size and weight. The shell consists of a hard-rubber case *a*, threaded externally to engage an internal screw thread on the hard-rubber ear piece *b*. The magnets are built up of flat steel rings *c*, so magnetized that the opposite sides of their circumferences are of different polarities. To the north and south poles, respectively, are attached the **L**-shaped pole pieces *d*, which carry the magnet coils. The diaphragm is of thin iron and is clamped between the body *a* of the shell and the ear cap *b*.

INDUCTION COILS

8. Fig. 7 shows an induction coil of the type commonly used in a subscriber's station equipment. It is mounted on a wooden base, which is provided with four metal terminals, to which the ends of the primary and secondary windings are attached by solder. This is one common way of bringing out the wires of the windings so as to protect them from breakages and also facilitate connecting them into the circuits of the instrument.

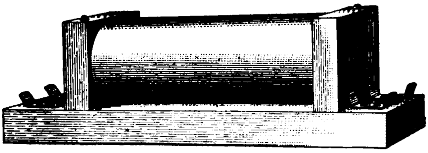


FIG. 7

Fig. 8 shows a similar coil in cross-section; *a* indicates the core, which consists of a bundle of soft-iron wires, *b* the primary coil, and *c* the secondary coil. In the construction shown in this illustration, the winding terminals *1*, *2*, *3*, and *4* are mounted directly on the wooden heads of the coil instead of on a base.

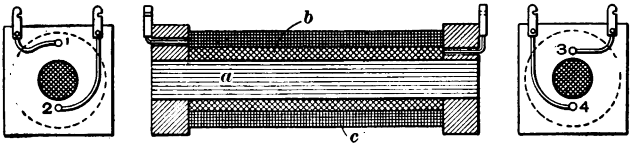


FIG. 8

RINGERS

9. As previously explained, the polarized ringer operates with alternating current. In the ringer commonly used by the Bell companies, Fig. 9, the entire structure, including the supports for the gongs, is mounted on a soft-iron plate, or yoke *a*. This yoke is arranged for clamping against the inside of the front board, or door, of the telephone instrument, as shown in Fig. 1 (*b*), by means of the clamping screws *b*, Fig. 9, which pass through the board. The bells are outside of the front board and are mounted on posts *c*, which pass through the board and are adjustably clamped in the yoke. The distance of the bells from the tapper can thus be adjusted as may be necessary. The magnet cores and the yoke, to which they are attached, form a horseshoe magnet, and the armature *d* is pivoted between the upturned ears of a brass yoke *e*. The two yokes *a* and *e* are rigidly fastened together and spaced by two posts *f*, which are provided with locknuts for adjusting the spacing, or the distance of the pivoted armature from the pole pieces. The permanent magnet *g*, which is in the shape of a shallow **U**, is rigidly secured to the central part of the yoke *a*, from which it passes down behind the magnet coils, its lower end bending forwards so as to lie close to, but not touch, the armature. The rod carrying the bell tapper is rigidly attached to the armature.

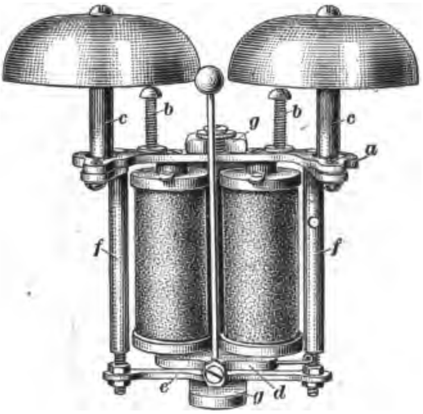


FIG. 9

10. The armature and magnet cores are polarized by the permanent magnet; both ends of the armature are of one polarity and the adjacent ends of both cores are of the polarity opposite that of the armature. Alternating current in the coils forms poles of unlike polarity at the ends of the cores and these polarities change simultaneously. The combined effect of the permanent magnet and of the coils is to strengthen alternately the flux in one core and weaken or reverse that in the other core. The polarized armature thus rocks on its pivot and the bell rings.

The polarized ringer is simple and reliable. It has no contacts to be made and broken, and for any given adjustment it will respond to a very wide range of current strengths and frequency variations.

11. A biased ringer is one that operates with pulsating current, that is, current with one continuous direction but with periodical change of strength. By adding a *biasing spring a*, Fig. 10, to a polarized ringer, the ringer becomes biased. The spring tends to pull the tapper against one bell. Current pulsations that pull the tapper against the other gong then cause the bell to ring, but pulsations that tend to pull the tapper in the same direction as the spring would not cause a ring. The ringer must therefore be biased for the direction of current in the line. A ringer of this kind is useful in telephone substation work, because it provides a means for selecting between two instruments in the same circuit. Thus, if two oppositely biased ringers are placed in series in the same circuit, one of them will respond only to positive pulsations and the other only to negative pulsations.

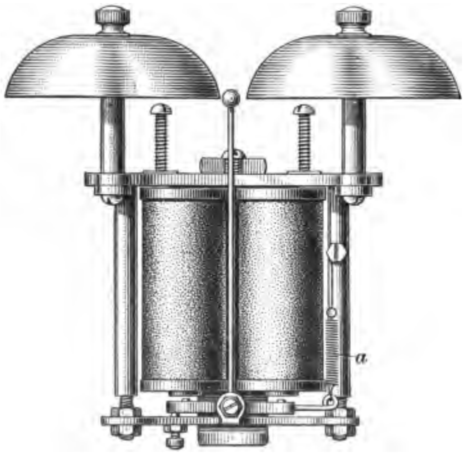


Fig. 10

MAGNETO GENERATORS

12. Figs. 11 and 12 show two common forms of **magneto generators,** or magnetos, the first having three bars, or magnets, and the second five. Three-bar magnetos are satisfactory for short lines and small exchanges, and even two-bar magnetos will answer in some cases. A two-bar magneto has the same outside dimensions as the three-bar type, but does not have the middle bar. The heavier four- and five-bar generators are employed on country lines, where a large number of instruments may be bridged across the same line.

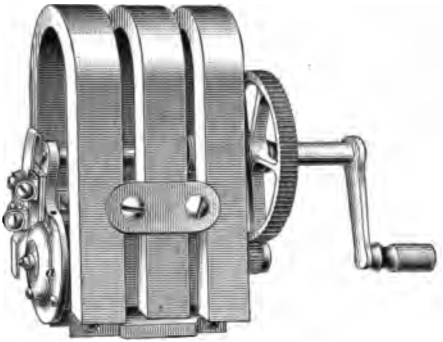


FIG. 11

13. The construction is essentially the same in all sizes. The armature is journaled between end plates, one of which can be seen at *a*, Figs. 11 and 12, and can be rotated between the poles of the magnets by means of a crank. The movement of the crank reaches the armature through a gear and pinion, so that the armature turns very much more rapidly than the crank.

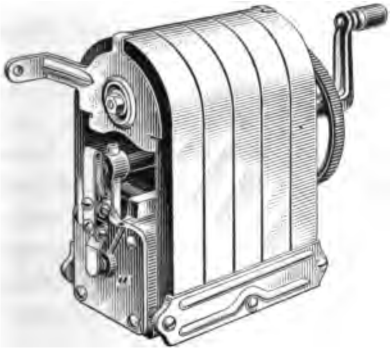


FIG. 12

The principal features of construction of magneto generators can be seen in Fig. 13. The armature core *a* is either of soft cast iron or of a built-up structure of soft steel punchings, in which case it is called a *laminated core*. The slots *b* and *c* of this core are filled with the armature winding, consisting of many turns of insulated copper wire. Only a few turns are shown in order to indicate more clearly the manner of connecting the terminals of the coil. One end of this winding is directly connected to a pin *d* driven into the body of the core, and is therefore permanently grounded to the framework of the machine. The other end is connected by means of a pin *e* with a pin *f* inside the shaft. Pins *e* and *f* are insulated from the shaft, and pin *f* projects against a spring *g* with which one terminal *g'* of the generator is connected. The other generator terminal *h'* is connected with a spring *h*. Both springs *g* and *h* are mounted in insulating material *i*, and the circuit of the generator is normally open at the gap between the spring *h* and the end of the shaft *j*. When the crank is turned, the shaft is forced endwise enough to close the circuit, thus forming the automatic cut-in previously referred to.

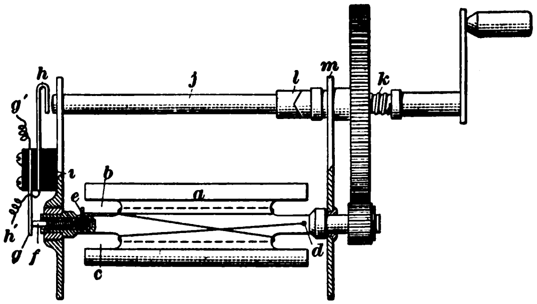


FIG. 13

14. The shaft is held away from the contact spring by a coiled spring *k*. This shaft fits loosely in the hub of the gear and carries a rigidly attached collar *l*. Between this collar and an extension of the wheel hub are **V**-shaped surfaces through which torque is transmitted to turn the wheel when the crank is turned. The hub turns in a bearing in the plate *m*, but is prevented from moving endwise. Before the wheel begins to turn, the **V** surfaces move on each other and force the shaft endwise enough to close the circuit.

The circuit through the generator may be traced as follows: terminal *g'*–spring *g*–pins *f* and *e*–armature winding–pin *d*–frame of generator–spring *h*–terminal *h'*. When the operator ceases to turn the crank, the contact with spring *h* is automatically opened by the action of the spring *k*.

HOOK SWITCH

15. The construction and operation of the type of hook switch most commonly used by the Bell companies in the wall type of instrument is illustrated in Fig. 14. The hook lever *a* turns on a pivot *b*, and this pivot is attached to a bracket *c* secured to the inside of the telephone woodwork. The telephone circuits are completed through three German-silver platinum-pointed contact springs *d*, *e*, and *f*, the latter spring having a curved end that rests against the lug *g* on the hook lever. When the receiver is placed on the hook, the lever is drawn down to the limiting position determined by the bottom of the slot in the plate *h*. The lug *g* then forces the spring *f* to the right, removing the pressure from springs *d* and *e*, which come to rest against springs *i* and *j*. The contacts between *d*, *e*, and *f* are thus broken, and the only circuit left closed is through the bell for receiving signals. The springs *i* and *j* do not enter into the electrical circuits. When the receiver is removed from the hook, as shown, the contacts between springs *d*, *e*, and *f* are brought together, and the local and line circuits are closed for talking purposes.

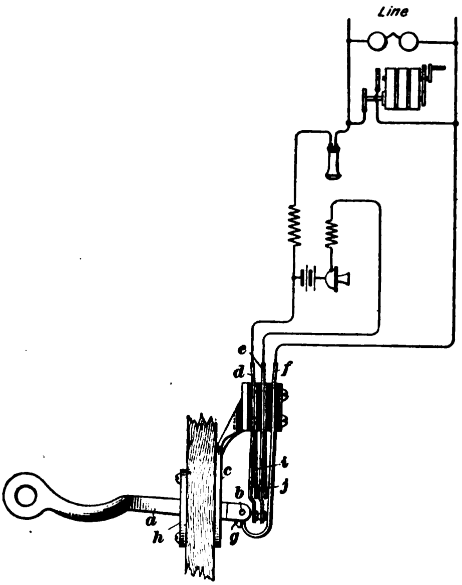


FIG. 14

LOCAL BATTERIES

16. The dry battery is best adapted for service in practically all subscriber's station work. The internal construction of a common form of dry cell is shown in Fig. 15. A zinc can forms both the containing vessel and one electrode. The carbon electrode occupies the center of the vessel and is surrounded by absorbent material, which is saturated with sal ammoniac solution. The contents of the can are covered with a coating of pitch to prevent evaporation, and the outside of the can is insulated by a paper cover. Repairs are very rarely worth while on such cells; when they fail, new cells are substituted.

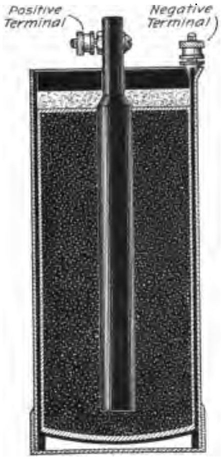
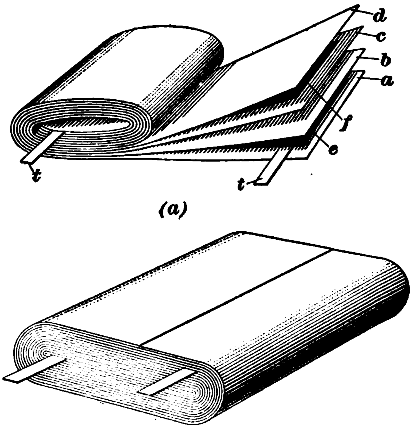


FIG. 15

CONDENSERS

17. Fig. 16 (*a*) shows the construction of a *rolled condenser* of the type universally used for telephone purposes. Four long strips of thin bond paper *a*, *b*, *c*, and *d*, and two long strips of tin-foil *e* and *f* are rolled together. The strips of tin-foil are somewhat narrower than the strips of paper and are placed between the first and second, and the third and fourth strips of paper, as indicated, thus bringing two layers of paper between the adjacent layers of tin-foil. Thin strips of metal *t* are laid adjacent to the respective layers of tin-foil during the process of rolling and are allowed to project from the finished roll, as



(*a*)

(*b*)

FIG. 16

shown in Fig. 16 (*b*), to form terminals. The roll is boiled in hot paraffin so as to impregnate it thoroughly and expel all moisture. While hot, it is subjected to heavy pressure, thus expelling all superfluous paraffin and bringing the plates very close together. When completed, it is placed in a sealed can and presents the appearance shown in Fig. 17.

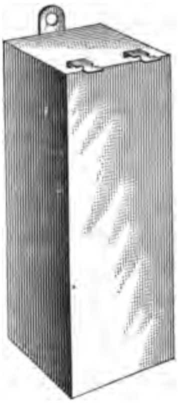


FIG. 17

18. The practical unit of capacity of condensers is the *microfarad*. The condensers mainly used in telephones range from 2 microfarads down. Larger capacities may be obtained by connecting as many condensers in multiple as may be required. The resulting capacity is the sum of the capacities so connected.

TYPES OF SUBSCRIBERS' INSTRUMENTS

MAGNETO, OR LOCAL-BATTERY, INSTRUMENTS

19. Subscribers' instruments may be classified generally as *magneto*, or *local-battery*, *sets* and *common-battery sets*. Each of these general classes includes *wall sets*, which may or may not be provided with a shelf for writing, and *desk sets*, in which the receiver, transmitter, and hook switch are portable in form for ready handling by the telephone user.

20. Magneto Wall Sets.—Fig. 18 is the circuit diagram of a standard magneto wall set such as illustrated in Fig. 1. When the receiver is on the hook, the contacts *a*, *b*, and *c*, Fig. 18, are held apart by the hook-switch action. When the receiver is removed from the hook, these contacts close, thus completing both the local circuit containing the transmitter, battery, and primary of the induction coil, and the talking circuit of the line, including the receiver and secondary of the induction coil. In this instrument the bell and the generator are bridged across the line, the generator circuit being open at all times except when closed by the automatic cut-in when the generator is operated.

21. **Magneto Desk Sets.**—By mounting a receiver, transmitter, and hook on a stand, connected by a cord to a bell box, as shown in Fig. 19, a form of instrument more convenient for some uses than the one just described is obtained. The bell box contains the ringer, the magneto generator, and the induction coil. The battery, as a rule, is concealed at some point near the bell box, being connected to suitable terminals thereon by wires not shown. The principle of the desk set is identical with that of the wall set, but the circuit details are necessarily varied to permit the separation of the transmitter, receiver, and hook switch from the other parts. The desk stand may be kept on top of the user's desk and the bell box placed under or beside the desk at a point where the magneto handle will be within easy reach of the subscriber. The upright portion of the stand is hollow and contains the hook-switch spring and also

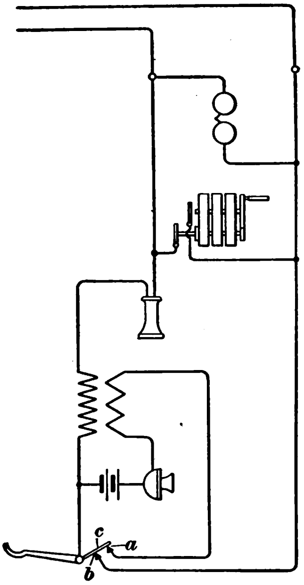


FIG. 18

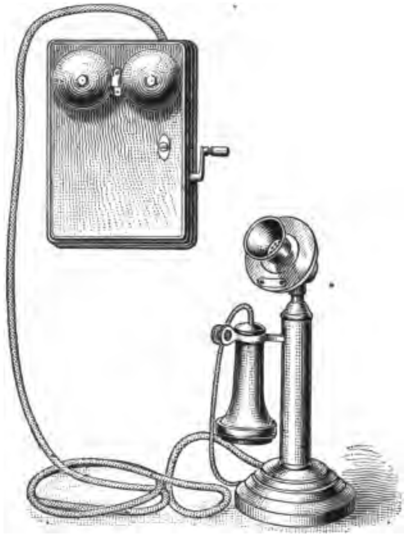


FIG. 19

a metal strip with terminals for the three conductors of the bell-box cord and the two conductors of the receiver cord. By removing a screw from the plate on the bottom of the desk stand, the stem containing the hook switch, transmitter, and terminals can be removed from the upright part for making adjustments or connections.

22. Fig. 20 shows the circuits of a magneto desk stand when the receiver is on the hook. When the receiver is removed, the contacts *a*, *b*, and *c* are brought together, closing both the talking circuits, one through the transmitter and one through the receiver. To avoid mistakes in connecting the cord between the stand and the bell box, the insulation on the wires contained in the cord is colored, as indicated on the diagram. The various terminals in the desk stand, and also in the magneto box, are marked with initial letters *Y*, *R*, *W*, and *G N*, to indicate which of the conductors should be attached to them. Thus, the letter *W* in the desk stand indicates that the white receiver cord is to be attached. The telephone worker must pay strict attention to these colors and markings, as they greatly facilitate making proper connections.

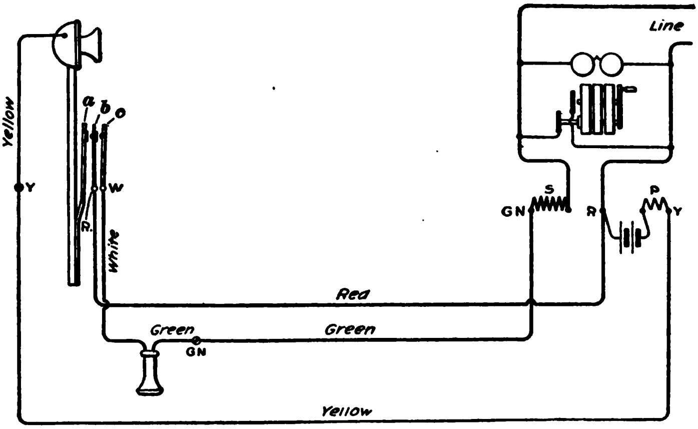


FIG. 20

23. When the receiver is off the hook, the primary circuit can be traced from the battery through the red cord–contacts *b* and *a*–transmitter–yellow cord–primary winding *P* of the induction coil–battery. Talking into the transmitter varies the resistance of this circuit and thus varies the current in it. The varying current in this primary circuit induces electromotive forces in the secondary circuit and can be traced through the secondary winding *S*–green receiver cord–receiver–white cord–contacts *c* and *b*–red box cord–line. Talking into the transmitter thus sets up line currents that affect the distant receiver. Incoming voice currents caused by talking into some distant transmitter follow the path through the receiver, in which they are translated into sound waves. The connection of the generator and ringer in this magneto desk set are the same as in the wall set, Fig. 18.

COMMON-BATTERY INSTRUMENTS

24. The subscriber's station equipment used in the common-battery, or central-energy, system includes neither a local battery nor a magneto generator and is therefore simpler than in the magneto equipment A **common-battery wall set** is shown in Fig. 21 and its circuit diagram in Fig. 22. In common-battery systems a storage battery, usually 24 volts, is bridged across the line at the central office. When a subscriber lifts his receiver he closes a circuit at his hook switch, as indicated in the diagram, causing electricity to flow through the line relay in the central office. The relay closes the lamp circuit and causes the lamp to light. When the line is switched for use by the insertion of a plug into the jack, the battery supply is through a cord circuit. In either case electricity will flow through the circuit of the line while the receiver is off its hook, but no circuit for battery current exists when the receiver is hung up.

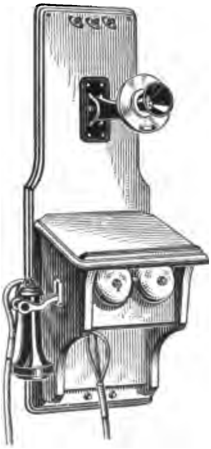


FIG. 21

25. The circuits shown in Fig. 22 may be best understood by referring to the simplified diagram of Fig. 23, from which the ringer is omitted. Electricity from the battery at the central office follows one limb of the line to the binding post L_2–transmitter–hook lever–primary winding *P* of induction coil–binding post L_1 and back to the central office over the other limb of the line. The condenser is charged to the same difference of potential as that existing at the transmitter terminals.

When the transmitter is in use the vibrations of its diaphragm vary the line resistance and thus vary the line current. Varying current in the transmitter circuit causes varying charge in the condenser and alternating current is set up in the circuit including the condenser and winding *S* of the induction coil. This alternating current in winding *S* causes induced electromotive forces in winding *P*, which augment, or boost, the current impulses caused by the action of the transmitter diaphragm.

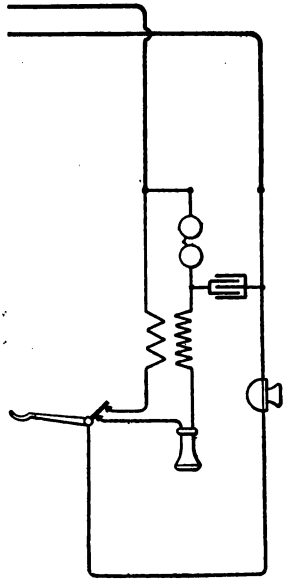


FIG. 22

26. Incoming voice currents from the distant station, which are alternating currents superposed on the direct steady line current, pass from one side of the line to the other through the transmitter and winding *P*, Fig. 23, of the coil. The induction in winding *S* causes alternating currents in the path including the receiver, the transmitter, and the condenser. This local circuit is thus active both when transmitting and when receiving.

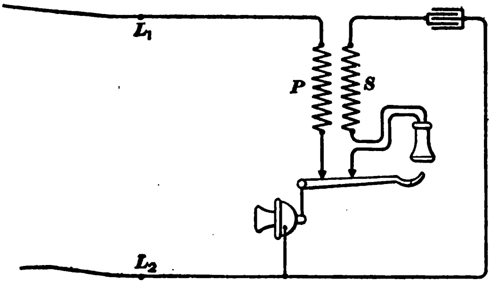


FIG. 23

The path of ringing currents from the central office is shown in Fig. 22, namely, one limb of the line–the condenser and bell in series–the other limb of the line to the central office.

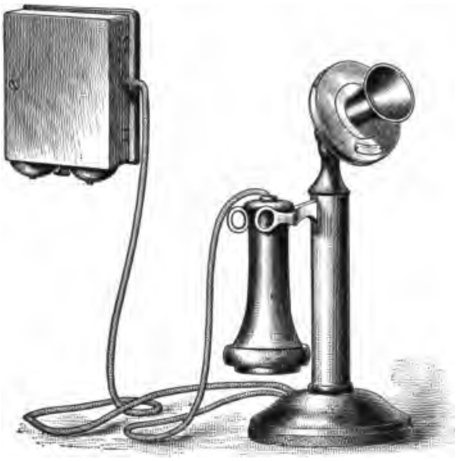


FIG. 24

27. A common-battery desk set, Fig. 24, may employ the same desk stand as is used with magneto desk sets. The common-battery bell box resembles the magneto *bell box* in appearance, but it is usually much smaller on account of the absence of the generator. The circuit diagram, Fig. 25, for a typical common-battery desk set, together with the explanation already given, should make the connections of this set clear.

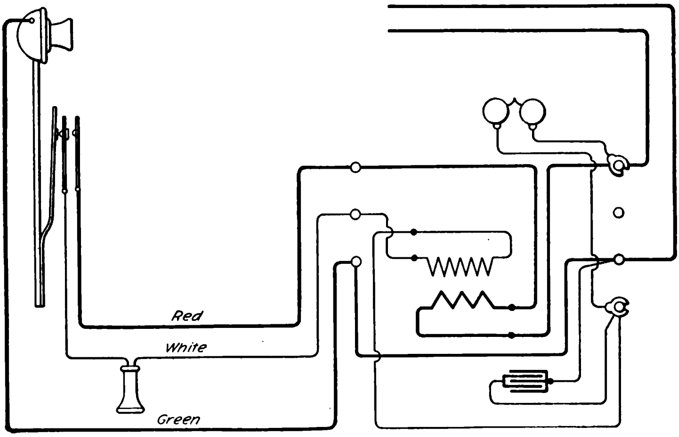


FIG. 25

28. A **hotel set** is a small compact telephone developed especially for use in hotels and apartment houses. One of these instruments is shown in Fig. 26 and its circuit connections in Fig. 27. The two separate circuit diagrams shown, though wholly different in appearance, represent identically the same set of circuits. The more complicated diagram in Fig. 27 (*a*) shows the wiring as it actually exists, and to a certain extent shows the various parts of apparatus in their relative positions. The diagram in (*b*) aims solely at circuit simplicity; no attempt is made to show the parts in their actual positions, and all such parts as binding posts, hinges, and flexible cords are omitted. The first diagram

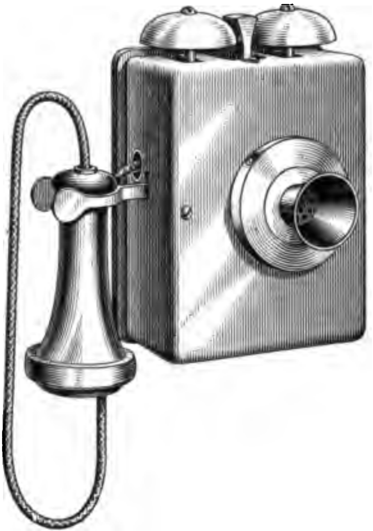
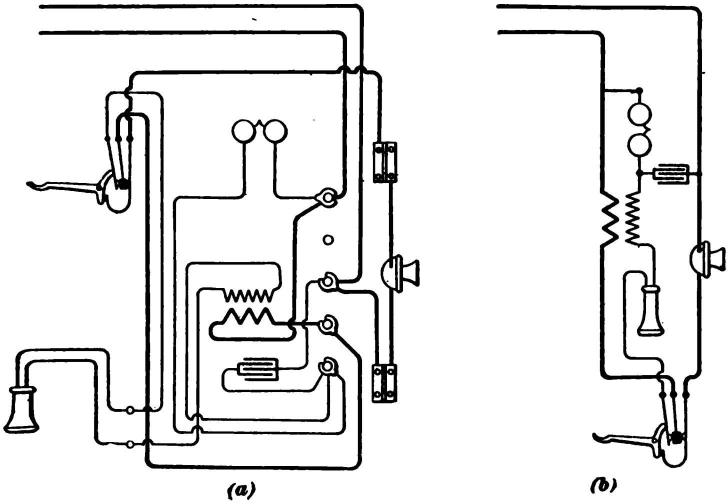


FIG. 26



(*a*) (*b*)

FIG. 27

is useful to show the relative locations of parts, and the second to afford the simplest and easiest understanding of the action of the circuit.

PARTY-LINE TELEPHONES

MAGNETO PARTY LINES

29. The ordinary magneto instruments of the wall and desk types already described are adapted for use on party lines, on which they are merely connected to the line in multiple. All of the ringers are then permanently bridged across the line, as can be understood by studying Figs. 18 and 20. Each bell magnet forms a small leak from one side of the line to the other through which voice currents may pass. Were it not for the very high impedance of the bell-magnet coils to the rapidly fluctuating voice currents, several of these leaks in multiple would seriously interfere with the telephone transmission. In order to prevent the leakage of voice currents through the bell magnets as much as possible, the magnet coils are wound with fine wire and with a great number of turns. When thus used for bridging work on party lines such magnets usually have a resistance to direct current of from 1,000 to 2,500 ohms and an impedance to alternating current very much greater. The placing of a reasonable number of bells across the line does not then appreciably interfere with the transmission of voice currents.

30. Magneto party lines are used to a very small extent in city work. They are, however, largely used in connection with lines extending from towns or villages out into rural districts, such lines being called *rural lines* or *farm lines*. On these rural lines, when one bell rings, all ring. It is necessary, therefore, to adopt what is called code ringing, in order that each party may distinguish his call. Code ringing is accomplished by various combinations of long and short rings. Thus, the code for one station may be two long rings, that for another station one long and one short ring, and so on.

COMMON-BATTERY PARTY LINES

31. In city exchange work where common-battery systems are employed, the usual practice is to connect not more than four parties on a line and in some cities not more than two. With these limitations, the circuits of the instruments can be easily arranged so that any bell on a line may be rung to the exclusion of all the others. This is called *selective ringing.*

If the number of parties on a line is limited to two, selective ringing may readily be accomplished with ordinary polarized bells, one bell being connected between one limb of the line and ground and the other between the other limb of the line and ground. Either bell alone may be rung by sending alternating current over the proper line wire with a ground return.

32. A modification of this plan enables selective ringing to be extended to four stations. In this case, a pair of oppositely biased bells, already described, are connected between each side of the line and the ground; that is, one bell of each pair is adapted to respond to positive and the other to negative impulses only. In this way, if positive pulsations are sent over one line wire with a ground return, one of the bells connected with that wire will be rung. Negative currents over this same

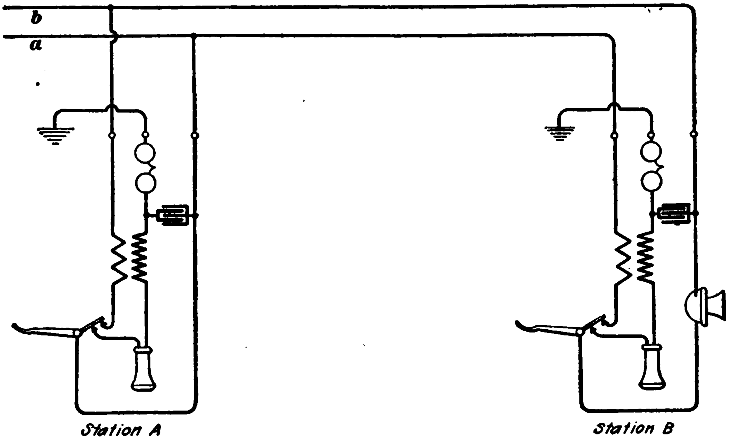


FIG. 28

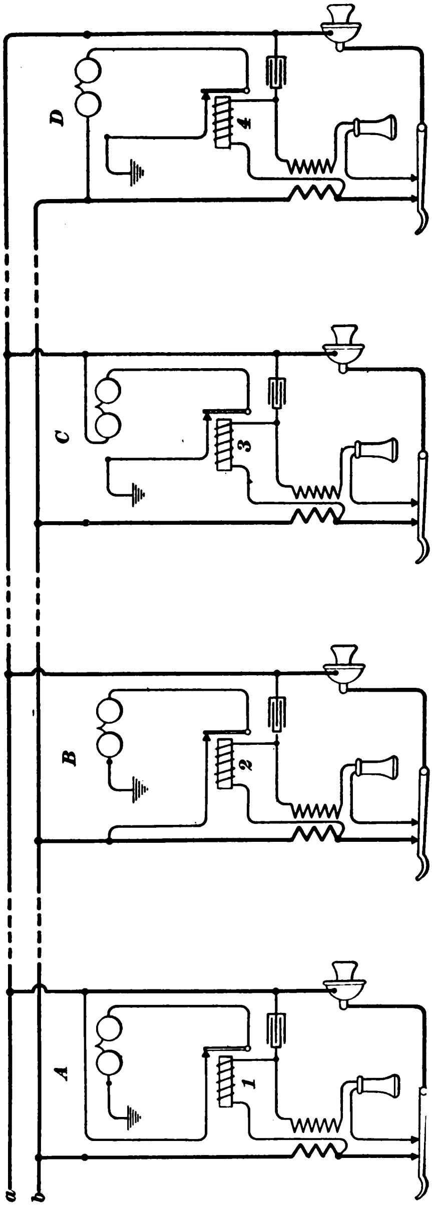


FIG. 29

wire will ring the other bell. In the same way, the choice between the bells on the other line wire can be made by sending positive or negative currents over that wire.

33. Two-Party Line.—The arrangement of instruments for two-party line selective ringing on common-battery lines just referred to is shown in Fig. 28. Each bell is connected between one limb of the line and ground rather than across the metallic circuit, in this respect only differing from the wiring shown in Fig. 22. Selective ringing is accomplished with the connections of Fig. 28 by grounding one pole of the generator at the central office and connecting the other pole to one side of the line or the other, according to which bell is to be rung. If the ungrounded terminal of the generator is connected to line wire *a* when both receivers are on their hooks, a circuit will be established through the condenser and bell at station *A*, but no circuit will be completed through station *B*. The reverse will be true if the ungrounded terminal of the generator is connected to line wire *b*.

34. Four-Party Line.—The circuit connections for selective ringing on a four-party common-battery line are shown in Fig. 29. The instruments for this system are wired similarly to those of the common-battery instruments previously considered, except that each includes a relay connected as shown. The bells of stations *A* and *C* are oppositely biased and are connected in local circuits between the line wire *a* and the ground; the bells of stations *B* and *D*, also oppositely biased, are connected between the line wire *b* and the ground. All the hook switches are shown in the positions taken when the receivers are off the hooks.

The ringing keys at the central office are arranged so that either positive or negative pulsating current can be established in either line wire, the other side of the ringing machine being simultaneously grounded. At the same time that current is set up in either side of the line, the other side of the line is grounded at the key. In order to ring the bell at station *A*, positive pulsations are set up in the limb *a* of the line, and the limb *b* is grounded at the office. The influence of this current on the condensers causes alternating currents in the relay windings *1*, *2*, *3*, and *4*, returning to the ground at the central office over the limb *b*. All of the relays are therefore energized, pulling up their armatures, closing their local circuits, and establishing at each station a temporary ground connection through the bell. Current from limb *a* of the line can then reach the ground through the bells at stations *A* and *C*, but only the bell at station *A* will respond, because it alone is biased for positive pulsations. In order to ring station *C*, negative current pulsations are established in limb *a*, and in order to ring stations *P* or *D* positive- or negative-current impulses must be established in limb *b*, while limb *a* is grounded at the key.

SUBSCRIBERS' MULTI-STATION SYSTEMS

EXTENSION TELEPHONES

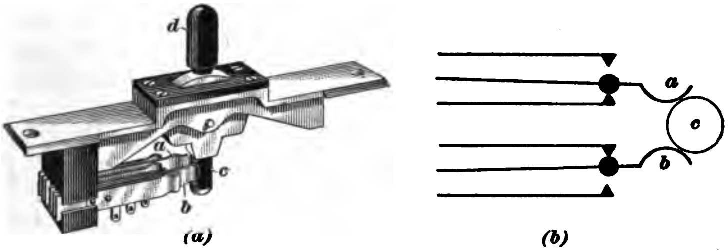
DESCRIPTION

35. The simplest form of the multi-station system consists of a main telephone with a second telephone added as an ***extension***, so that calls may be answered and received from different locations in the same premises. The most complicated form is that of the private branch exchange, which consists of a complete telephone exchange within the premises of the subscriber for intercommunication between the stations in the premises as well as for communication with the general public through the central office of the telephone company furnishing the service.

36. The simplest arrangement of extension telephones is composed of two ordinary common-battery instruments bridged across the same line. In this case both bells ring at once when a call is sent from the central office, and either instrument may receive or originate a call. If it is desired to have the call received only at one of the stations, the bell circuit at the other may be left open. If it is desired to have only one of the stations able to send a call, magneto telephones may be used and the generator omitted from the station that is to send no calls.

37. Frequently, however, somewhat different arrangements are desired by a subscriber to adapt the telephone service to some special requirements. To illustrate, a physician may wish to receive his telephone calls in his office during the daytime and in his bedroom at night, while in each case providing against intrusion by some one at the other instrument. This is but one of a large number of modifications that are sometimes desired by subscribers, and in many cases switches must be employed by which subscribers may alter their circuits at will.

The switches employed for this purpose are termed *cam switches* or *cam keys*, or merely *keys*, and are similar to the ringing and listening keys already briefly referred to in connection with switchboards. The cam switch shown in Fig. 30 consists of a group of platinum-pointed springs *a* and *b* with a plunger, or cam, *c* mounted on a lever *d* and adapted to play between the springs and move them from one alternate position to another, thus opening one set of contacts and closing another, as indicated in (*b*).



(*a*) (*b*)

FIG. 30

TYPICAL PLANS FOR EXTENSION TELEPHONES

38. Plan No. 1, Fig. 31, consists of a magneto telephone with one extension provided with a listening key *L K*. Normally, this key remains in the position shown, with contact springs *a* and *b* resting against their inner contact points. When the key is thrown, the springs are forced against the outer contact points, and the contacts with the inner points are broken. Normally, calls are received only at the main station, and only the main station can call the central office. When the key is thrown, calls are received at both stations, and either station can call the central office or the other station. An auxiliary bell can be bridged to the bell of either station or to the line.

39. Plan No. 2, Fig. 32, consists of a magneto telephone with one extension, each station having a key, which is shown in its normal position. Normally, calls are received only at the main station and only the main station can call the central office, but both stations can listen. By throwing its key *R K* the main station can signal the extension station, regardless

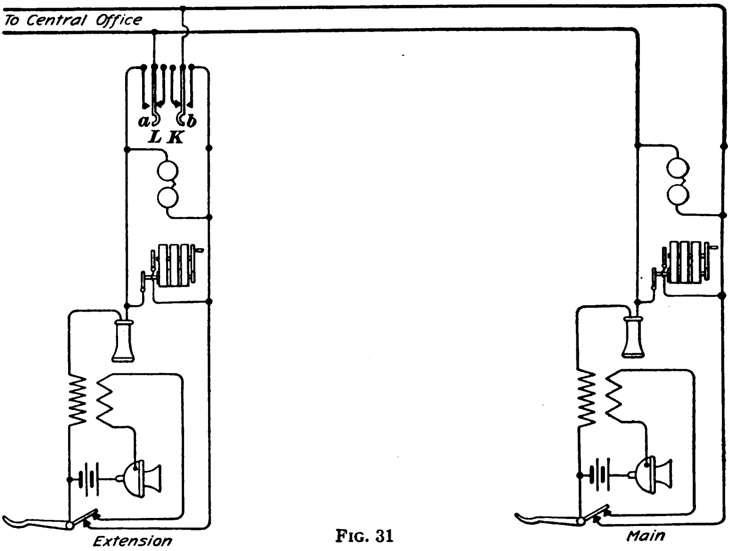


FIG. 31

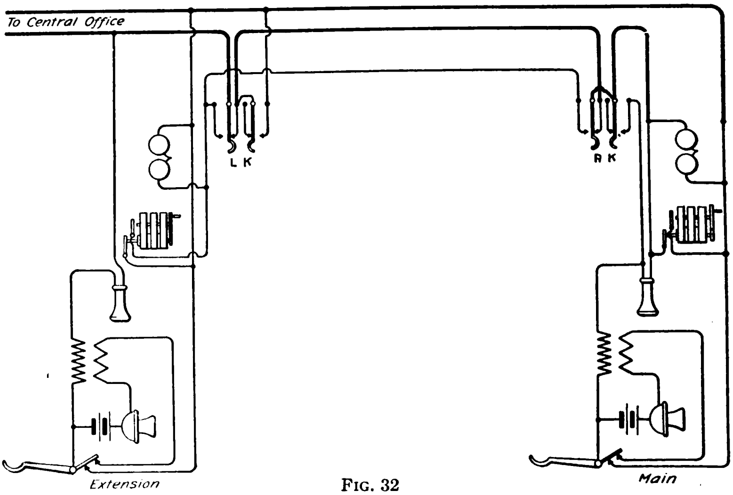


FIG. 32

of the position of the key *L K*. When the key *L K* is thrown, calls are received only at that station. The extension station cannot signal the main station except when the key *R K* is thrown; it can signal the central office by first throwing its own key *L K*. An auxiliary bell can be bridged to the bell at either station or across the line.

40. **Plan No. 3,** Fig. 33, consists of one magneto telephone with two extensions. The main station has two ringing keys normally resting in the position shown. Calls are received at the main station only, either from the central office or from any station. By throwing key *1* or key *2* the main station can signal station 1 or station 2. With the keys in normal position, any station can signal the central office, but the main-station bell will ring at the same time. All stations can listen in on the line at all times. An auxiliary bell can be bridged across any bell or across the line.

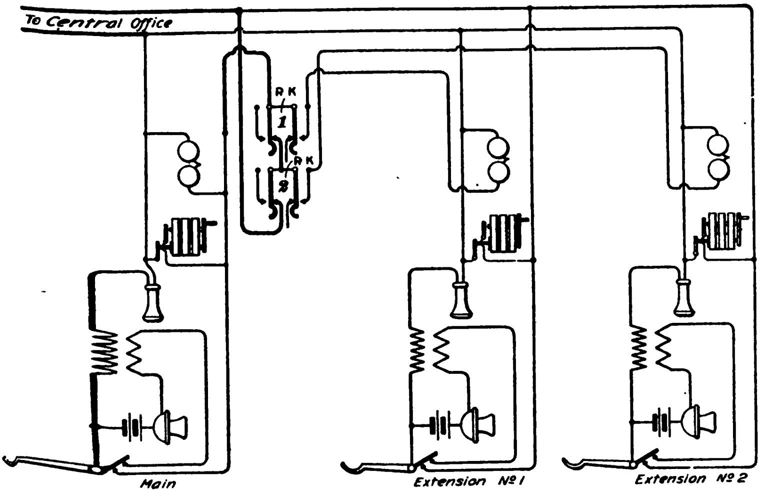


FIG. 33

41. **Plan No. 4,** Fig. 34, consists of one common-battery telephone with one extension. Central-office calls are normally received only at the main station, but if the key *L K* is thrown such calls are received only at the extension station.

The main station is shown equipped with a generator for signaling the extension station, but the extension station cannot signal the main station. Normally, both stations can signal the central office and converse with it; but if the extension key is thrown, the main station is completely cut off from central. An auxiliary bell can be connected in series with the bell at either station and a switch can be arranged to short-circuit this auxiliary.

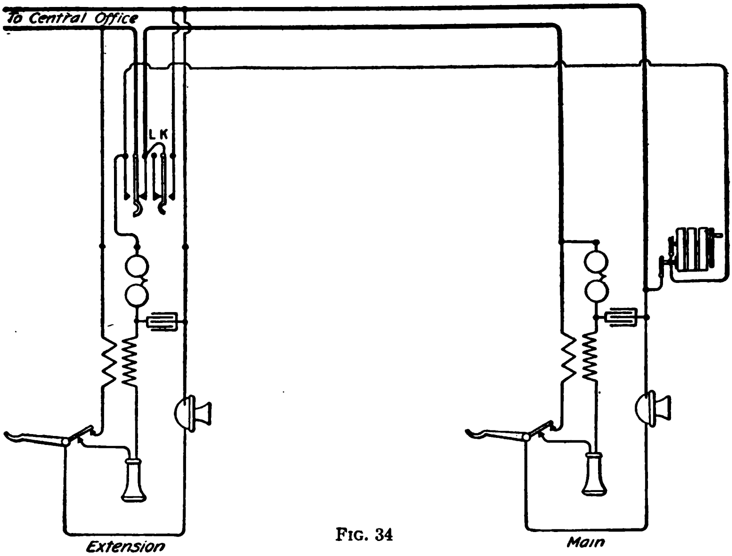


FIG. 34

42. Plan No. 5, Fig. 35, consists of one common-battery telephone with two extensions. Normally, calls are received only at the main station, but any station can call the central office and listen in on the line. The main station is provided with a generator and a ringing key *R K*, enabling it to signal either extension at any time. The extension stations cannot signal the main station nor each other. When the key *L K* at either extension station is thrown, calls are received only at that station, and the main station is cut off from central. Extension station No. 1 can cut off both No. 2 and the main station. Extension station No. 2 can cut off only the main station. An auxiliary bell can be connected in series with the bell

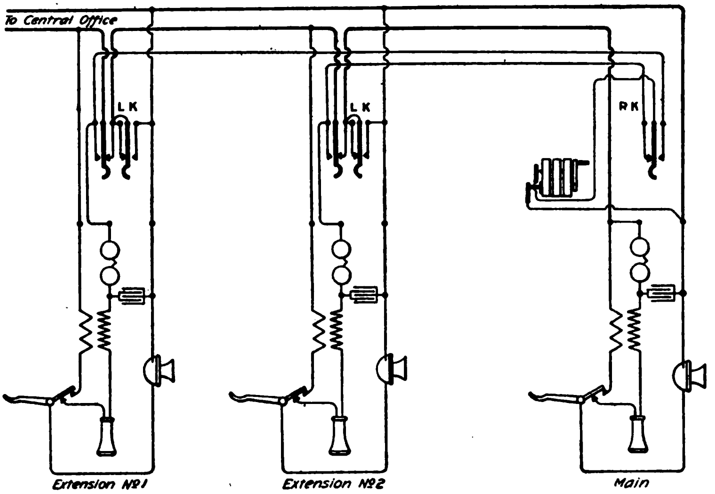


FIG. 35

of any station or be bridged across the line in series with a condenser. A switch can be arranged to cut out the auxiliary bell.

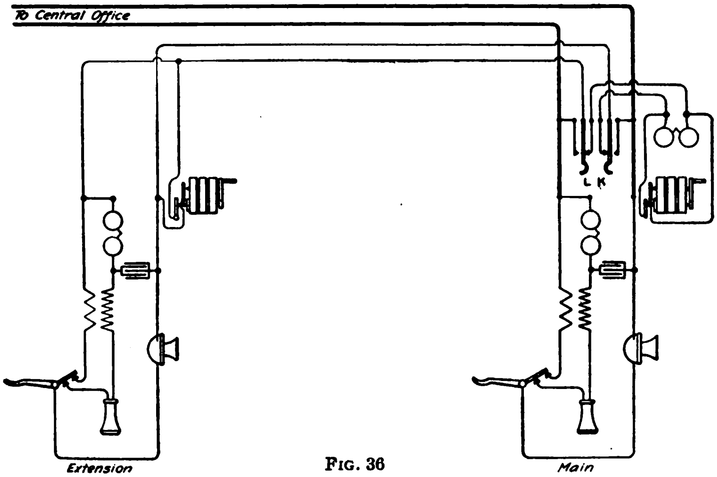


FIG. 36

43. Plan No. 6, Fig. 36, consists of one main common-battery station and one extension, each provided with a generator for signaling the other. Normally, calls are received only at the main station; but when the main station key is thrown, calls are received at both stations and the central office can be called from both stations by simply lifting their receivers. An auxiliary bell with a cut-out switch can be wired in series with either station bell.

PRIVATE BRANCH EXCHANGES

44. The commonly accepted abbreviation for the term private branch exchange is P. B. X. It is as well understood and proper in telephony as the abbreviation E. M. F. for electromotive force. The individual telephone stations connected with private branch exchanges will usually be referred to herein as *extensions*. They may also sometimes be called local stations and P. B. X. stations.

By means of the switchboard in a private branch exchange any two of its stations can be connected for conversation or any of its stations can be connected, through a trunk line leading to the central office, with any telephone in the main exchange, or over long-distance lines with telephones in other exchanges.

CORDLESS SWITCHBOARD

45. For small private branch exchanges, employing only a few stations and a few trunks to the central office, the so-called *cordless switchboard* has been developed and is widely used. It is termed cordless because no flexible cords with their corresponding plugs and jacks are used, all of the switching being done by cam switches; it is also sometimes called the *monitor board*.

Fig. 37 shows an external view of such a board adapted for three trunk lines to the central office and seven local stations. This board consists of eleven sets of keys, each set having three key levers arranged in a vertical row. The keys in the first three vertical rows at the left are for the three trunk lines leading to the central office, and immediately above them are mounted the electromagnetic drops forming the signals for those trunk lines. The next seven vertical rows of keys to the right are those for the seven local lines, and immediately above them may be seen the line signals, which are ordinary magnetic visual signals. The keys in the right-hand row form the operator's set, by means of which the operator's telephone may be connected with any line or with any pair of connected lines. Each key lever has two sets of springs exactly like those shown in Fig. 30, the long pair of springs in each set normally resting against their inside contacts, but being changed to rest against the outside contacts when the key lever is thrown to press them apart. These cordless, or monitor, boards are so designed that when a connection is made through the central office, the current for all signals and for both the operator's and the local station transmitters comes from the central-office battery over the trunk line in use, exactly the same as in a call of a direct central-office line. When, however, two local stations are connected for conversation, no trunk line is used and electricity for both the operator and the local stations is furnished over special wires, known as *battery feed-wires*. These extend to the central-office storage battery through suitable low-capacity fuses. These feeders are usually formed of one or more pairs of standard underground or aerial cable conductors. If the resistance of one pair of cable conductors is too high to permit the necessary current supply to the private branch exchange,

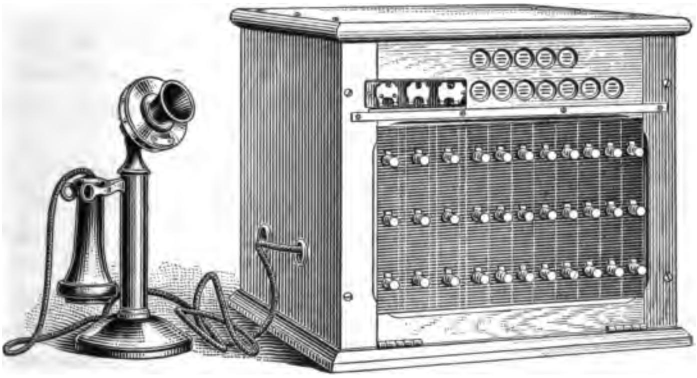


FIG. 37

then the conductors of two or more pairs are placed in multiple to constitute the battery feed.

Ringing current for the private branch exchange is usually furnished from the central office over another pair of regular conductors in the underground or the aerial cable. In some very small private branch exchanges ringing current is furnished by means of a small hand generator.

46. Circuits and Operation.—Fig. 38 is a diagram of the circuits of a cordless switchboard. For the sake of simplicity one trunk and five extension circuits are omitted; the omitted circuits are exact duplicates of those shown. The central-station battery circuit is connected between the terminals marked *battery* and *ground* in the lower left-hand corner of the diagram. The circuit from the source of ringing current at the central station is connected with the terminals marked ± and *G* in the lower right-hand corner of the diagram. Both these circuits may be metallic.

The terminals are indicated near the bottom of the diagram, the trunk terminals at the left and the extension terminals at the right. The circuit of each extension normally passes through the contacts of three keys in a vertical row and thence to the battery terminals, one side passing through a line signal and the buzzer relay. When the receiver is lifted at any extension station, the corresponding line signal and the buzzer relay are energized. The relay contact is in a local circuit, which also contains a *night key*, as indicated; by leaving this key thrown, a buzzer will sound when an extension receiver is lifted, thus causing both a visible and an audible signal at the switchboard. By leaving the night key in its normal position, only the visible signal will operate. The seven line signals are shown in Fig. 37 in a row immediately above the key levers at the right of the three trunk drops.

47. On perceiving the signal, the operator throws any one of the keys in the operator's row and a corresponding key of the calling line, as keys *a* and *b*, Fig. 38, so as to connect her telephone with the line, and on lifting her receiver she can talk with the calling station. If this station wishes connection with

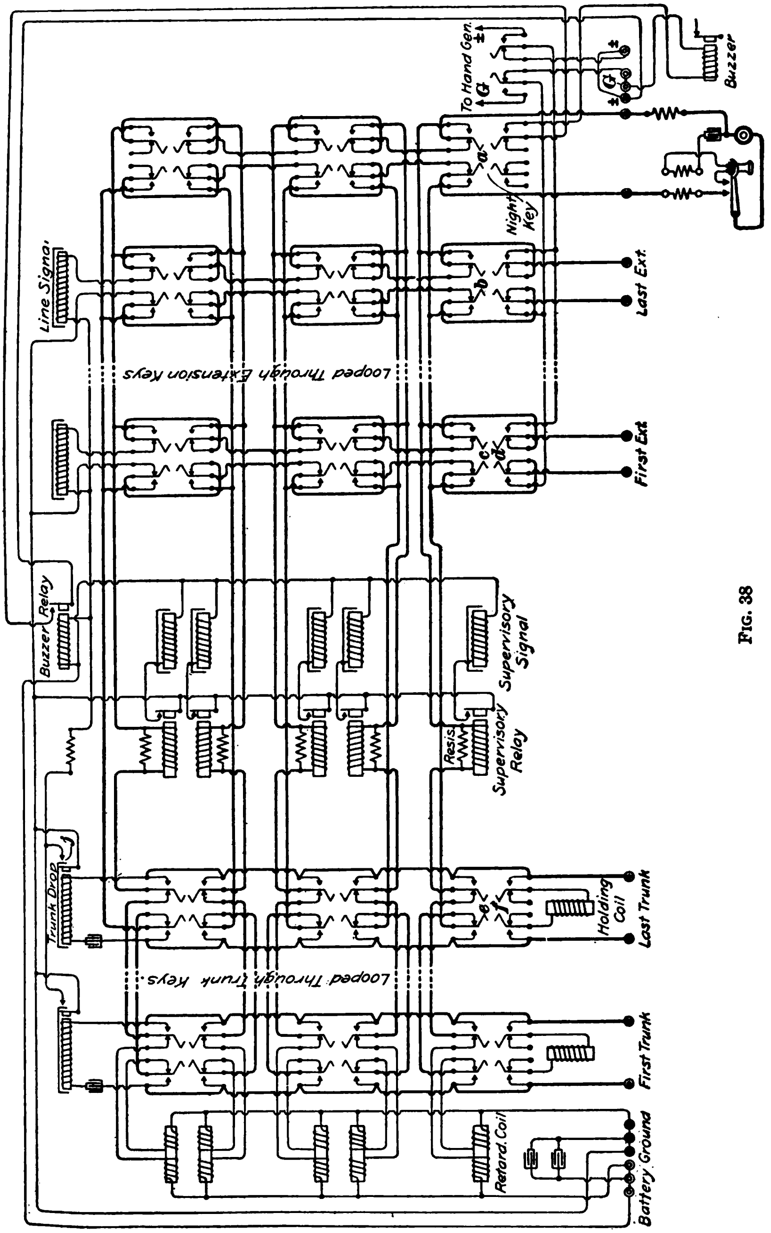

Line Signal
Buzzer Relay
Trunk Drop
Looped Through Extension Keys
Looped Through Trunk Keys
Supervisory Signal
Supervisory Relay
Resis.
Holding Coil
Last Trunk
First Trunk
Retard. Coil
Battery Ground
First Ext.
Last Ext.
Night Key
To Hand Gen.
Buzzer
G
a
b
c
d
e
f

FIG. 38

another extension, the operator throws the proper key, as *c*, and then momentarily closes the ringing key *d*, using the hand generator if necessary, so as to establish ringing current in the called line. When the called station responds, the operator can return her key *a* to its normal position, leaving the two subscribers' lines connected. Keys in any horizontal row can be used to connect stations in this manner.

If an extension wishes connection through a trunk circuit with the central office, the branch operator can connect the calling station directly with the central office by throwing the proper keys in a horizontal row, as *b* and *e*. Current through the trunk circuit and the receiver at the extension energizes the line relay at the central office and thus signals the operator there.

48. When two extensions are connected for conversation, talking current from the central office reaches them through retardation coils and a supervisory relay magnet. While this current continues, the supervisory relay holds a circuit closed through a supervisory signal. When the receivers at both extensions are hung up, the current ceases and the supervisory signal indicates to the branch operator that the keys can be returned to their normal positions. The resistor indicated in parallel with each supervisory relay is a part of the relay and consists of a non-inductive winding of German-silver wire on the core of the relay in parallel with the active winding.

49. A call from the central office is indicated to the branch operator by a trunk drop, which closes a contact, as at *j*, in the circuit of the buzzer relay. The branch operator then throws any two keys connecting her line with the trunk over which the signal comes, as keys *a* and *e*. Battery connection is now through the trunk, as key *e* opens the circuit through the retardation coils. On lifting her receiver the branch operator can learn from the central office what is desired and can then make connection with the desired branch station in exactly the same manner as already described when calling one local station for connection with another. The three trunk drops are shown in Fig. 37 at the left of the row of line signals.

50. By throwing a holding key *f*, Fig. 38, the branch operator places a holding coil across the trunk circuit, thereby holding the supervisory relay in the central office in operated condition, thus indicating to the central-office operator that the trunk is busy. In this way the branch operator can hold a trunk while making connections. The holding key is returned to its normal position as soon as the connections with the trunk are completed. When the supervisory relay indicates to the branch operator that the receiver at the local station has been hung up, all her keys used for this connection are returned to their normal positions.

The central office can be called by throwing any trunk key *e* and the corresponding operator's key *a* and then lifting the operator's receiver from its hook.

AUXILIARY DEVICES FOR CORD-TYPE BRANCH EXCHANGES

51. The cordless board just described cannot be adapted for large exchanges, because the many keys required would make it too cumbersome and expensive. The switchboard employing jacks, plugs, and cords is almost universally used where the combined number of trunks and local lines exceeds ten. Each line, whether a trunk extending to the central office or a line to the private branch substations, terminates in a jack on the face of the board. These jacks are in the form of switch sockets and the operator makes connection between her telephone and any line, or between any two lines, by inserting plugs in the jacks, the plugs being connected by cords.

JACKS AND PLUGS

52. Jacks are usually mounted in strips of ten or twenty; a strip of ten is shown in Fig. 39. Each of these jacks consists of a sleeve contact, which extends through the hard-rubber front strip and constitutes the socket for the plug, and several springs, which are engaged by the contacts of the plug to complete the circuits when the plug is thrust into the jack. The arrangement of the springs is shown in Fig. 40, which also shows how the plug cooperates with the various contacts in the jack.

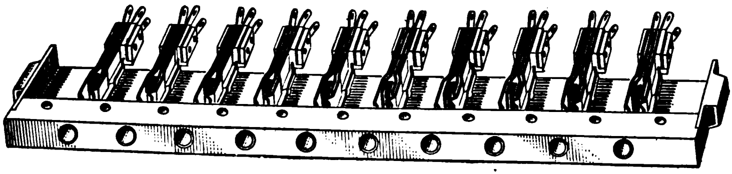


Fig. 39

This jack is typical of all jacks. The plug shown is of the three-contact type, each contact forming the terminal of a separate conducting strand in the cord. At *a* is shown the *tip contact*, at *b* the *ring contact*, and at *c* the *sleeve contact*. The parts of the jack are similarly named, *d* being the *tip spring*, *e* the *ring spring*, and *f* the *sleeve*. As a general rule, the tip spring and the ring spring form the terminals of the two conductors of the telephone line, which consequently are called, respectively, the *tip side* and the *ring side* of the line. The sleeve contact of the jack is usually employed in connection with auxiliary circuits for operating local apparatus in connection with the various signaling and other functions of the switchboard.

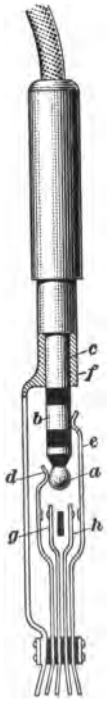


Fig. 40

53. The type of jack shown in Figs. 39 and 40 is known as a *cut-off jack*. The reason for this is that the springs *d* and *e*, Fig. 40, normally rest against two inner springs *g* and *h*, so that the circuit of the line is normally continued through those springs to other parts of the switchboard. When, however, the plug is inserted into the jack, the springs *d* and *e* are lifted out of contact with the springs *g* and *h*, thus cutting off the circuit that normally extends through these inner springs.

Jacks can be made to perform other and more complicated switching functions, as is frequently necessary, by adding other springs, so that various circuit changes are produced by the movement of the tip and ring springs when the plug is inserted or withdrawn.

54. In making circuit diagrams of switchboards, conventional diagrams are employed for jacks, as shown in Fig. 41. View (*a*) shows the simplest arrangement of tip and ring contact springs and a sleeve adapted to engage the corresponding parts of a three-conductor plug. These springs perform no other function than to make and break contacts with the plug. View (*b*) shows springs that are lifted from one set of contacts when making contacts with the plug, as explained in connection with Fig. 40. Fig. 41 (*c*) indicates a jack in which two contacts are broken and one, in addition to the plug contacts, is made when the plug is inserted. Views (*d*), (*e*), and (*f*) show other possible combinations.

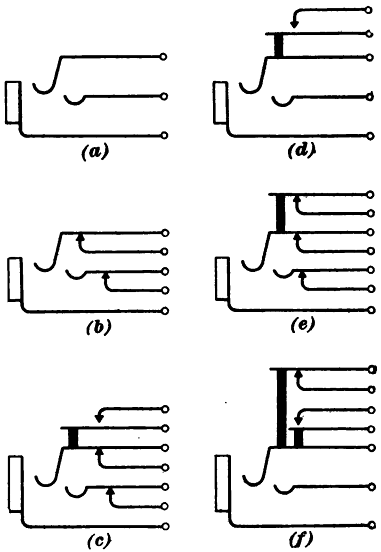


FIG. 41

55. The more complicated forms of jacks are usually employed only in small boards, such as private-branch-exchange boards. In large boards, on account of the very great number of jacks employed, the jack itself is made as simple as possible and part of the switching functions are performed by means of relays, which may be mounted separate from the board. These relays, operated as an incidental function by inserting a plug into a jack, or withdrawing it, enable a comparatively simple jack and jack circuit to control more complicated switching functions than could possibly be provided for in the jacks.

CORDS

56. The cords used in switchboards consist of separate flexible conductors insulated from each other and covered with a braiding of linen or cotton. The cords usually employed have three separate conductors, known as the *tip*, *ring*, and *sleeve conductors*, corresponding with the contacts on the plugs. Sometimes these conductors are composed of concentric layers of steel wire, spirally wrapped to give the necessary flexibility. In other cases they are composed of woven strands of tinsel. These are known as *steel cords* and *tinsel cords*, respectively.

The cords are the most perishable part of the switchboard. The first point of failure is just back of the plug where the cord conductors usually break or become short-circuited.

LINE SIGNALS

57. Three types of signals are used on private-branch-exchange switchboards; namely, the ordinary *mechanical drop* that must be restored by the operator after each operation, the self-restoring *visual-target signal*, and the *electric lamp* with either direct-line connection or local-circuit connection with line relay control.

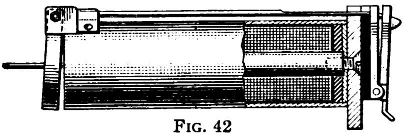


FIG. 42

58. Mechanical-Drop Signals.—The construction of the **electromagnetic drop** frequently employed on private-branch-exchange boards is shown in Fig. 42. This is known as the tubular drop, a name derived from the fact that the electromagnet is enclosed in a tube of soft iron which forms a return path for the magnetic lines of force and also a mechanical protection for the winding of the coil. A strip of five such drops is shown in Fig. 43. In Bell practice the strips usually contain ten drops or are long enough to provide for ten.

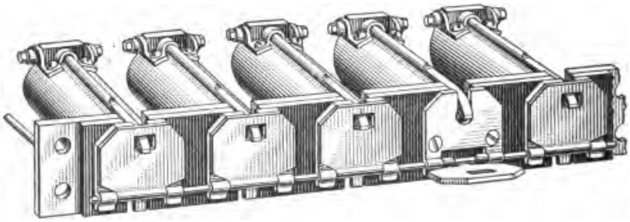


FIG. 43

The main reasons for providing these drops with a tubular shell of iron is to minimize electromagnetic induction between adjacent drops and to give them high impedance. The lines of force follow the path of least reluctance through the shell and thus do not interfere with neighboring electric circuits; high impedance prevents any appreciable amount of voice current from being shunted through the magnets when several of them are bridged across the line at the switchboard.

59. A pair of **night alarm contacts** may be associated with each drop so that they will be closed when the drop falls. If the operator leaves the board, these contacts can be made part of a circuit through an audible signal that will sound when a drop falls. When the operator is present this circuit can be readily opened so that the audible signal will be inactive.

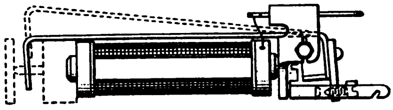


FIG. 44

60. Visual-Target Signals.—The construction of one form of self-restoring visual target signal is shown in Fig. 44, and the general appearance of a number mounted is shown in Fig. 45. Another form is shown in Fig. 46, the construction being shown in (*a*) and the general appearance in (*b*). In the form of signal shown in Figs. 44 and 45 a target rises into view when the magnet is energized and drops back behind a shield when the magnet is deenergized. The coils are cut out of circuit by the act of plugging into the line, making a tubular shell unnecessary, as the coil is excited only momentarily while signaling.

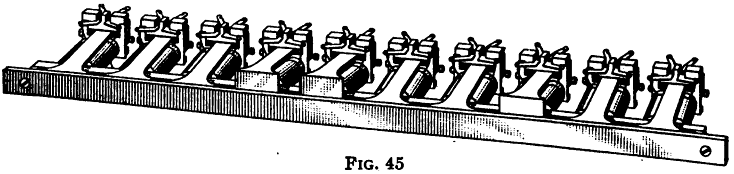


FIG. 45

61. When the magnet of the signal shown in Fig. 46 is energized the target rises a very short distance, bringing white stripes on its face opposite horizontal slots in the shield; when the magnet is deenergized the target drops back so that black stripes are opposite the slots. These signals are provided with tubular shells similar to those on the magnets of automatic drop signals and for the same reasons, namely, because they are mounted side by side and are energized during conversation.

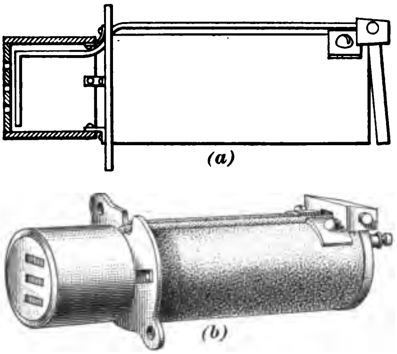


FIG. 46

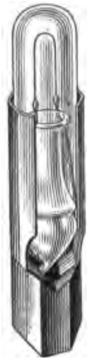


FIG. 47

62. Signal Lamps.—A type of signal lamp, shown in Fig. 47, has been especially developed for switchboard signaling. The lamp does not screw into its socket or base, as in the case of the lamp used in commercial lighting, but rather slides between two springs, which are so mounted as to form proper terminals for the wiring leading to the lamp. These springs form part of the receptacle, or *lamp jack*, as it is called, and such jacks are usually mounted in strips, as shown in Fig. 48, with spacing corresponding to the line jacks. In front of each lamp is mounted a small lens of the type shown in Fig. 49 (*a*). This lens, because it is of opalescent glass, is commonly referred

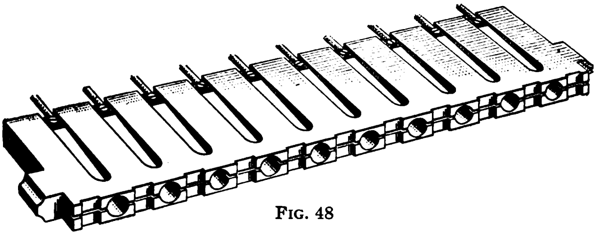


FIG. 48

to by switchboard men as an *opal*. The brass collar in which it is mounted is adapted to slip and be held by friction in the opening of the lamp jack. If the opal is mounted on the horizontal key shelf or plug shelf of the switchboard, it is sometimes protected by means of a metal guard or shield, as shown in (*b*), in order to prevent breakage by the plugs. Lamps used for cord or supervisory signals are always relay controlled.

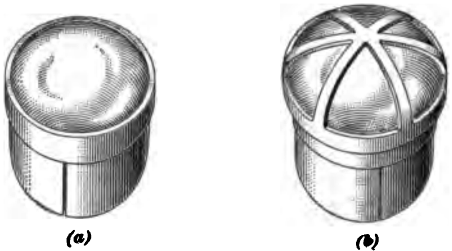

(*a*) (*b*)

FIG. 49

RELAYS

63. A relay is an electromagnet so arranged that movements of its armature open and close electric circuits. Relays used in connection with private-branch-exchange lines are of the type shown in Fig. 50, namely, a single-coil magnet with a pivoted armature, adapted to make a single contact when attracted, and therefore said to have a *single-make* contact. Screws are provided, as shown, for adjusting the back and the front stroke of the armature. These relays are usually mounted in strips of ten, the entire group being enclosed in dust-proof rectangular cases.

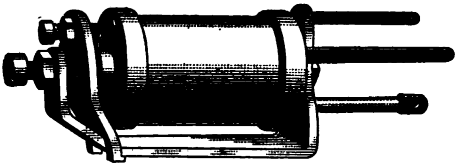


FIG. 50

The type of relay used in cord circuits is shown in Fig. 51. Each relay is enclosed in an individual copper shell for preventing cross-talk, for reducing impedance, and for guarding against mechanical injury or the entrance of

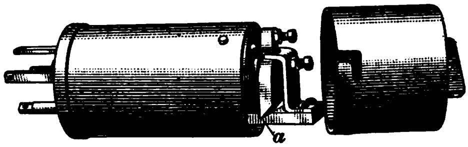


FIG. 51

dust. The armature is of the tilting type, resting on a knife edge shown at *a*. When the armature is attracted it closes a front contact and opens a rear contact, thus giving rise to the name *make-and-break relay*.

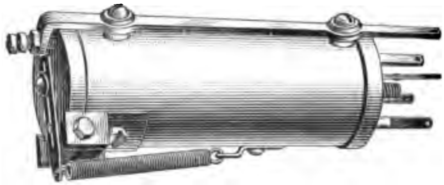
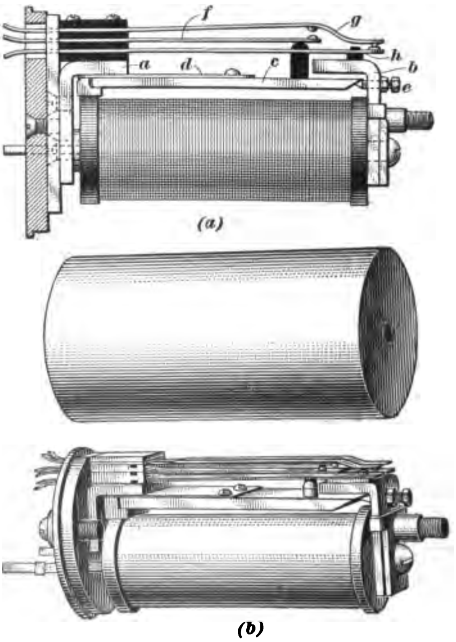


Fig. 52

64. Two types of relays are used in connection with the trunk circuit at a private-branch-exchange board. One is a single iron-clad relay, as shown in Fig. 52, having a pivoted armature pulled back by a coil spring, the tension of which is adjustable. This relay is particularly adaptable for use where a firmly closed back contact is desired. It is adapted to make one contact and break one; that is, it has a *single-break contact*.



(a)

(b)

Fig. 53

The other type of relay used in this connection is shown in Fig. 53, view (*a*) showing the construction and (*b*) the finished appearance with the shell removed. This relay is adapted for a wide variety of purposes, particularly where a number of contacts must be made and broken. A single core is provided with two **L**-shaped pole pieces *a* and *b*. An armature *c* extends parallel with the coil and is secured to the under side of the rear pole piece by a spring *d*. Normally, gravity holds this armature down against the inner end of an adjustment screw *e*; but when the coil is energized the armature is pulled up against the pole piece *b*. The spring *f* is then forced up into contact with the upper spring *g*, which is thus raised out of contact with spring *h*. Contact between springs *f* and *g* is made before contact between *g* and *h* is broken, thus giving the name *make-before-break contact.*

Usually two sets of springs like *f*, *g*, and *h* are operated by this relay, and sometimes it operates three such sets of springs; it is therefore often called a *double-make-and-break relay* or a *triple-make-and-break relay*, according to the number of contacts.

65. In order to become accustomed not only to the names of different relays but also to the conventional diagrams used to represent them, as in Fig. 54, it would be well to practice making such diagrams, or sketches, so as to indicate both the type of winding on the electromagnet and the arrangement of contacts. Ordinarily, in making a diagram of a relay, the electromagnet may be indicated by showing a bar for the core and a line passing spirally around it for the winding, or more than one set of spirals if the relay has more than one winding. The various contacts may be arranged in connection with the armature of this bar in such way as to suggest the various makes and breaks that occur, due to the movement of the armature.

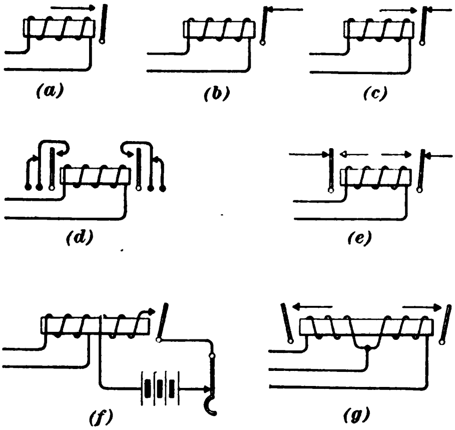

(a) (b) (c)
(d) (e)
(f) (g)

FIG. 54

Fig. 54 (*a*) represents a single-make relay, (*b*) a single-break relay, (*c*) a single-make-and-break relay, (*d*) a double-make-before-break relay, (*e*) a double-make-and-break relay, (*f*) a relay having a *locking coil*, a key being shown in the locking circuit to accomplish the final release of the armature, and (*g*) a double-wound relay, having its windings in such direction as to annul each other when both are energized. In the relay shown in (*f*), one winding causes the armature to close the circuit of the locking coil through a battery and the contact remains closed until the key is opened. The winding shown in (*g*) is called *differential;* the contacts close when one winding alone is energized and open when both are energized.

Other forms of conventional diagrams may be readily devised to show any combination of circuit changes. Although several of the conventional symbols show two armatures for the relay, this is purely a convention, the relay usually having only one armature. The reason for showing two in certain cases is that it makes the diagram easier to follow from the circuit standpoint.

MAGNETO PRIVATE BRANCH EXCHANGE

66. The **magneto private branch exchange,** employing cords and plugs, which differs in no respect from a regular magneto exchange board, is of little importance in the telephone industry, because any institution large enough to support a cord-type private branch exchange usually merits the installation of a common-battery exchange even though the main exchange with which it is associated is of the magneto type. In some cases the private branch exchange exceeds in size and importance the main exchange. One large summer hotel located in a small town has a private branch exchange with more stations than there are people in the town.

COMMON-BATTERY PRIVATE BRANCH EXCHANGES

67. Cord-type common-battery private-branch-exchange boards that employ mechanical drops and other magnetically operated visual signals are largely used, because of their simplicity. They usually require no local battery, all their operating current being derived either over the trunks or over separate charging leads. Another and more complex private-branch-exchange board, employing lamp signals, requires more current than the mechanical signal boards and frequently, though not always, is provided with a local storage battery. This battery is usually charged from the main-office battery, current being supplied either over separate charging leads or over the trunks when not in use for talking, or possibly over both.

NEW YORK TYPE NO. 1 BOARD

68. A mechanical-signal private-branch-exchange board largely used by certain Bell companies, and known as **New York Type No. 1,** is shown in Fig. 55. This board employs drops of the general type shown in Fig. 43 as the trunk-line signals, and visual signals of the type shown in Fig. 44 as the extension-line signals. The supervisory or cord signals are of the gridiron type, shown in Fig. 46.

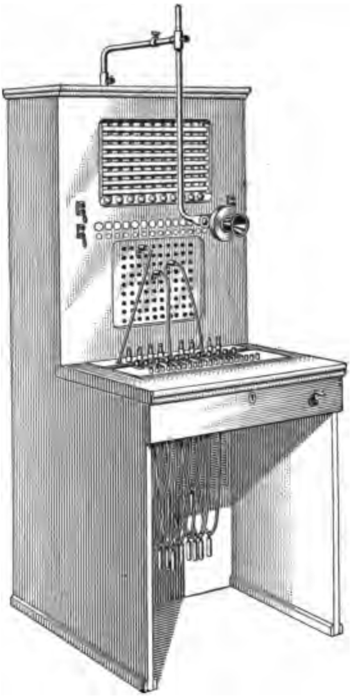


FIG. 55

69. The circuit of this board is shown in Fig. 56, in which a single trunk line is shown at the left and a single extension line at the right. The cord circuit is shown occupying the intermediate space between the trunk line and the extension line; the tip, ring, and sleeve contacts of the plugs are separately shown, as at *T*, *R*, and *S*, in order to indicate more clearly their relative circuit connections.

The trunk circuit consists of a single pair of wires leading to the distant central office. These wires terminate at that office

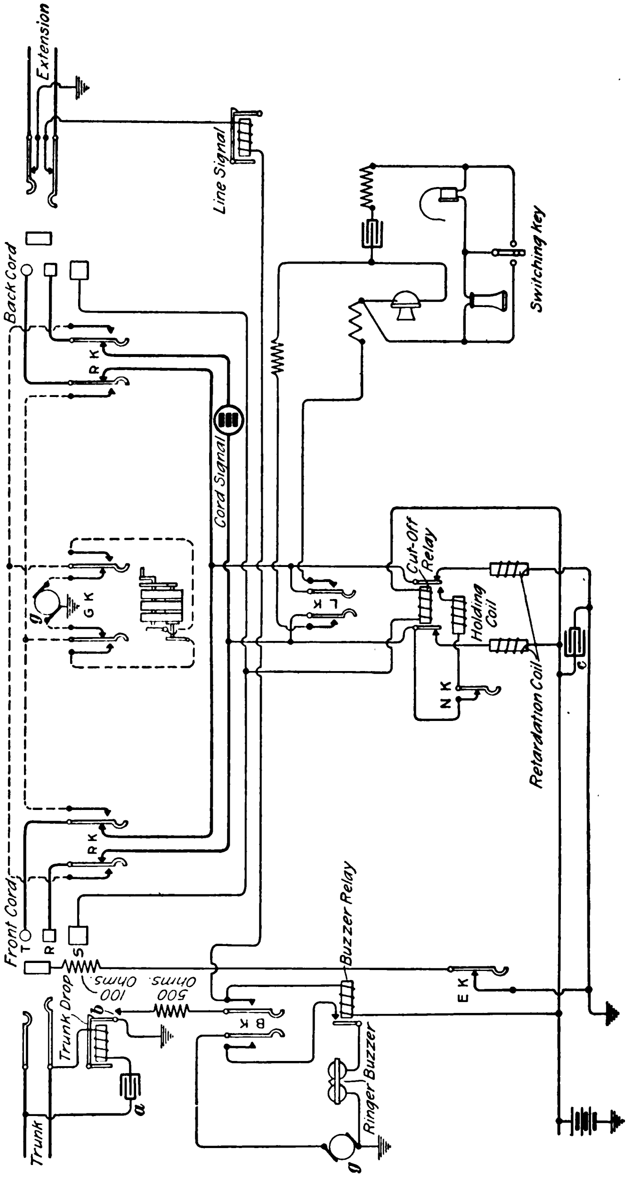

Extension
Line Signal
Back Cord
R K
Switching Key
Cord Signal
g
G K
L K
Cut-Off Relay
Holding Coil
N K
Retardation Coil
c
Front Cord
T
R
S
Trunk Drop
100 Ohms
500 Ohms
b
a
Trunk
B K
Buzzer Relay
Ringer Buzzer
g
E K

FIG. 56

on the switchboard in exactly the same manner as an ordinary subscriber's line circuit. At the private-branch board they terminate in the tip and the ring contacts of the jack, and bridged between them is the trunk drop in series with a condenser *a*. The purpose of this condenser is to keep the path across the line normally open to direct current and still permit the passage of alternating current to throw the drop and give a visual signal when the central office calls.

70. Associated with the shutter of the trunk drop is a pair of night-alarm contacts *b* that are closed when the shutter falls. On leaving the board, the operator closes the battery key *B K*, and when the drop falls it then completes a circuit from the battery through the buzzer relay–battery key *B K*–resistor–contacts *b*–ground. The buzzer relay then closes a circuit containing the ringing generator, the ringer buzzer, and a contact of the battery key, and the buzzer gives an audible signal in addition to the visible signal at the drop. The buzzer continues to sound until the drop is raised or the battery key opened.

71. In Fig. 56 and in diagrams given in subsequent Sections the symbols shown at *g* merely indicate connection with a generator feeder, or ringing-current feeder, from the central office, and do not indicate the use of a different generator at every place where the symbol is shown. The use of the symbol in this way simplifies the diagram. Practically the same statements can be made in reference to the battery symbol; it merely indicates connection with a battery feeder, or battery leads, from the central office. As a rule, in common-battery work, the several battery symbols on a diagram refer to the same battery, or to connections with one battery, unless the contrary is specifically stated. In telephone discussions the word battery is often used in the sense of electromotive force, or voltage; it indicates the presence of electromotive force. The positive, or ungrounded, terminal of the battery is called the *live terminal*, and the negative, or grounded, terminal is called the *dead terminal;* the sides of the battery feeder circuit are similarly named.

72. One extension line is shown in Fig. 56; its conductors are connected with the tip and ring contacts of the jack. The tip contact is normally grounded and the ring contact connected to the battery through a line signal and a buzzer relay except when a plug is inserted in the jack.

At the extension station is an ordinary common-battery instrument. Under ordinary circumstances, no electricity can flow through the line signal in the branch exchange; but as soon as the receiver at a station is removed, the circuit is closed and current from the battery energizes the line signal, causing it to indicate that a call exists on that line. The same current also energizes the buzzer relay, and if the battery key is closed the buzzer will sound. Thus, by leaving the battery key closed the operator will be called from any point within hearing distance, and the visual signal will advise her of the source of the call, whether from the central office or an extension station.

73. The cord-circuit diagram in the central portion of Fig. 56 shows that the tip and ring of the front, or answering, cord are normally connected, respectively, to the tip and ring of the back, or calling, cord through the contacts of the keys *R K* and that the path between the ring contacts includes the magnet of the cord signal. The sleeve contacts of the two plugs are connected together and to the battery, and the battery connection common to the two plugs includes the winding of a cut-off and holding-coil relay. This cord circuit includes a ringing key *R K* for each plug, so that the operator can connect the ringing generator with any line by simply plugging into the line and pressing the proper ringing key.

A generator key *G K*, shown in the center of the cord-circuit diagram, when in its normal position connects the central-office generator *g* (that is, the generator leads from the central office) with the back contacts of the two ringing keys, as shown by dotted lines. When, however, the generator key is thrown into its alternate position, the local hand generator is connected with the ringing keys. Thus, if there is a breakdown in the generator supply from the central office, the hand generator can be used.

74. Two methods of current supply are employed. When a subscriber is connected through a trunk to the main exchange, his transmitter receives current over the trunk from the main office. When, however, the extension subscribers are connected through a pair of cords, then the battery connection is through the cord circuit from the main-office battery leads or from a private-branch-exchange battery. When the current is thus supplied to two subscribers through the cord circuit, its path may be traced from the live side of the battery circuit through the left-hand retardation coil and back contact of the cut-off relay to the ring side of the cord circuit. Here the current divides, passing over the ring side of each subscriber's line through the transmitter at each of the two connected stations, thence back over the tip side of each line to the tip side of the cord circuit, where the two paths unite and pass through the right-hand back contact of the cut-off relay, the right-hand retardation coil to ground, and the other terminal of the battery. Usually, the two retardation-coil windings for one cord circuit are on one core, making in reality only one coil. Current is thus supplied to the two subscribers for talking purposes through the retardation coil or coils associated with the cord circuit. Current is supplied to other cord circuits from the same battery through other retardation coils. The retardation coils prevent variations of current, or voice currents, from passing, or leaking, from one cord circuit to another and thus causing cross-talk. These coils are provided with iron sheaths to give them very high inductance, so that the voice currents, instead of passing through them, as they would have to do to get from one cord circuit to the other, are confined to the circuit in which they originate. The iron shells for the retardation coils also prevent magnetic leakage between adjacent coils, which might cause cross-talk. In order further to reduce the tendency for cross-talk, a large condenser is sometimes bridged across the common leads from the battery, as shown at *c*.

75. By means of a listening key *L K*, Fig. 56, of which there is one for each cord circuit, the operator can bridge her talking set across the cord circuit and thus connect her telephone set with the circuit of any line. This talking set is shown in the lower right-hand corner of the illustration, and comprises a transmitter and receiver associated with an ordinary subscriber's station induction coil and condenser, so as to produce exactly the same talking circuit arrangement as has already been described in connection with a common-battery subscriber's station circuit. Both a head receiver and a hand receiver are shown; either may be used and the other shunted out of the circuit by means of the switching key.

76. Connections Between Two Extension Stations. The operation of the system can now be followed, assuming, first, that one extension station desires to converse with another connected with the same board. When the receiver of the first station is lifted from its hook, the corresponding line signal is displayed on the branch-exchange board, and the operator inserts the plug on the front, or answering, cord into the corresponding line jack. This cuts off the line signal and ground from the extension line. By throwing her listening key the operator connects her telephone set across the cord circuit, and both the extension station and the operator's set receive current from the battery through the retardation coils. Learning that another extension station is desired, the operator inserts the plug on the back, or calling, cord into the jack of that station, thus severing the connection between that line and its line signal. She then throws her ringing key *R K* associated with the back cord, thus connecting the line of the called station with the ringing generator and operating the bell at that station. When the ringing key is returned to its normal position, the two stations are left connected for conversation. When the receiver is lifted at the called station, the resulting current energizes the operator's cord signal and indicates the response. When the receiver is replaced, the cord signal again indicates that fact to the operator. In the connection between two extension lines, the cut-off and holding-coil relays do not come into play except that the back contacts are in the leads connecting the battery to the cord circuit.

77. Connections Between Central Office and an Extension Station.—A call from the central office to the private branch exchange would be made by the central operator plugging into the jack of the trunk at the main office and throwing her ringing key. The ringing current follows the path through the condenser *a* at the private branch exchange and operates the trunk drop. On seeing this signal, the operator at the branch exchange plugs into the trunk jack with one of the front, or answering, cords, thus establishing connection between the trunk and the cord. Connection is also established between the sleeve strand of the cord and the ground through the 100-ohm resistance and the exchange key *E K*, which are connected with the sleeve of the jack. A circuit from the live pole of the battery is thus established through the coil of the cut-off relay, the sleeve strand of the cord, the sleeve contact of the jack, and thence to the ground. This operates the relay, causing it to break both sides of the battery supply circuit that formerly existed through the retardation coils to the cords, and at the same time bridges the holding coil across the tip and ring sides of the cord circuit.

78. The reason for thus cutting off the battery supply to the cord circuit is that in the case of a connection with the central office, current for talking purposes is supplied from the central office over the trunk. The reason for connecting the holding coil across the cord circuit is to prevent the lighting of the supervisory lamp in the cord circuit at the central office when the connected party on the extension line hangs up his receiver or *flashes* his hook up and down. In other words, the purpose of the holding coil is to give the private-branch operator, rather than the private-branch subscriber, control of the supervisory signal at the main office. There are times when it is desired that the supervisory signal at the main office shall be under control of certain extension lines. An example of this is that at night it is often desired to leave certain lines plugged through to the central office. In this case, the night key *N K*, associated with the holding coil, is opened. With this key open, no bridge exists across the trunk line at the

CIRCUITS

LINE CIRCUITS

2. Two types of extension line circuits, indicated at *A* and *B*, Fig. 3, are employed in the non-multiple board. The circuit shown at *A* is of the direct-lamp type—that is, the lamp is included directly in the circuit of the line, so that when the receiver of the extension-station telephone is lifted, the line circuit will be closed through the lamp and the lamp will be

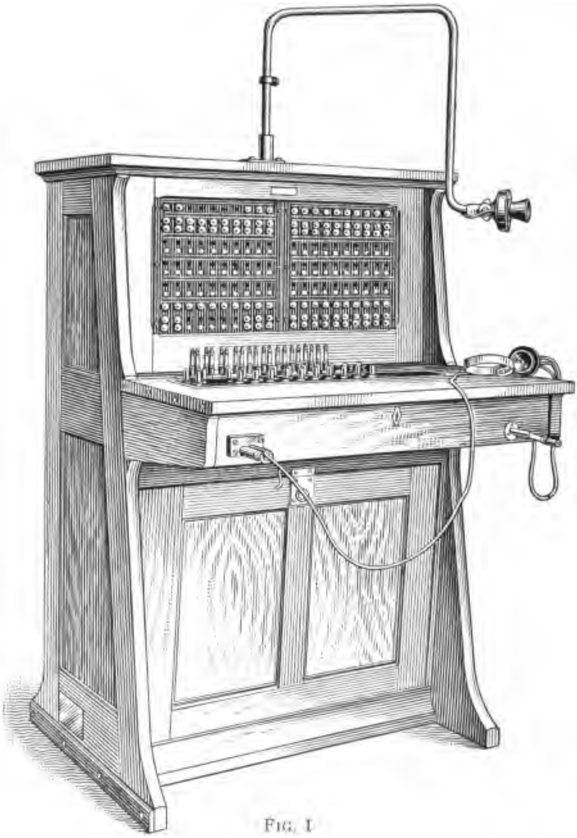
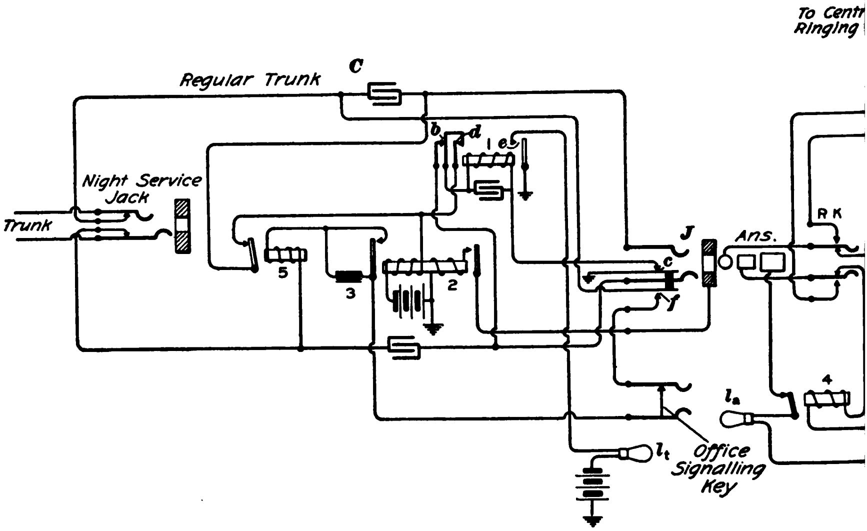
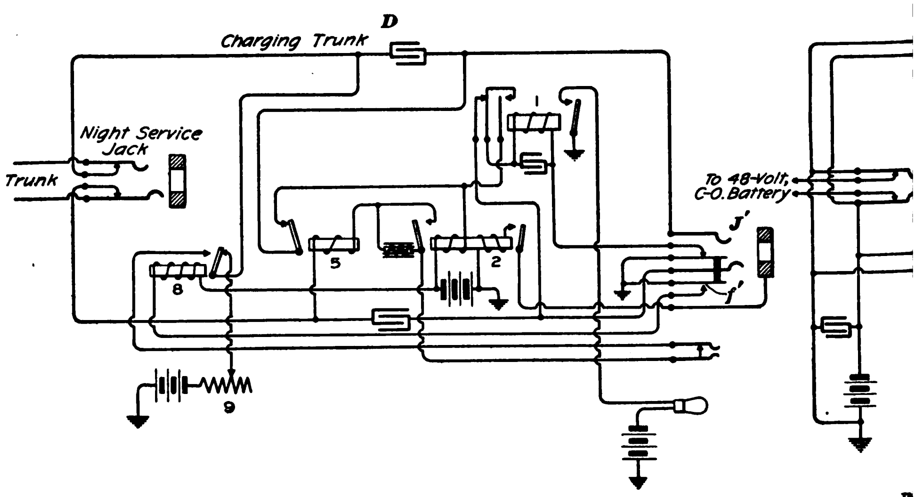
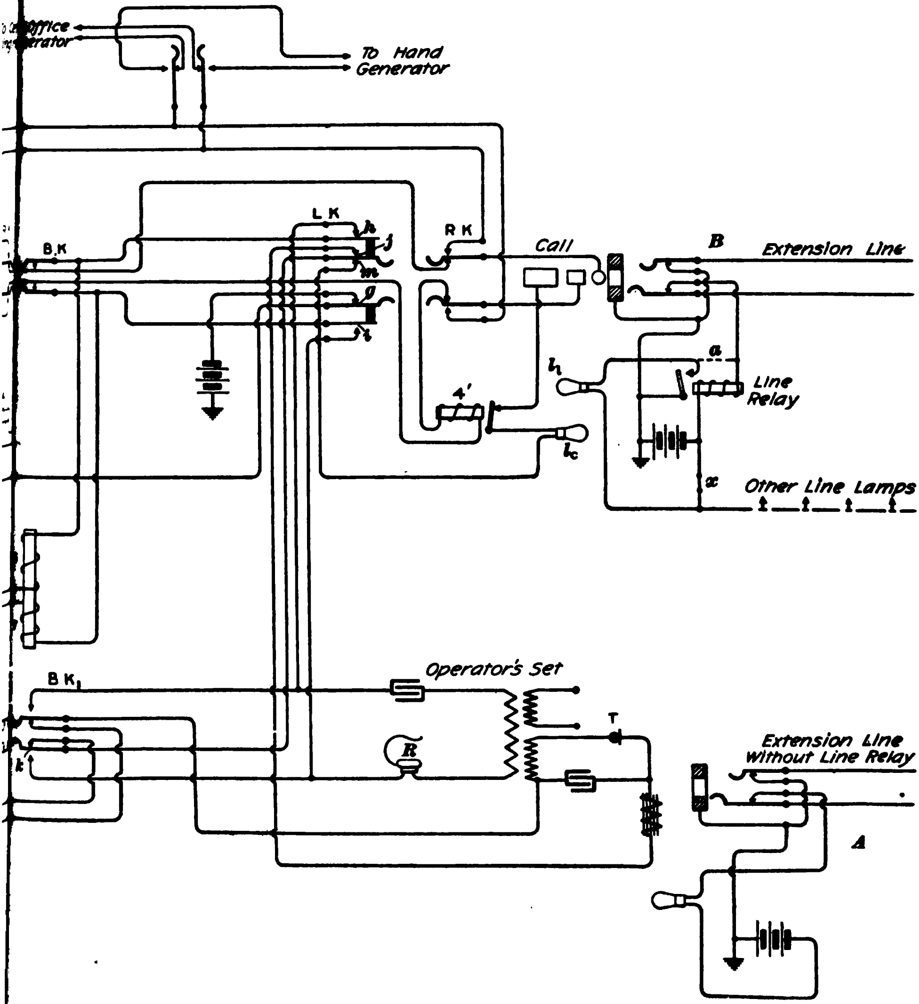


FIG. 1


To Centr
Ringing
C
Regular Trunk
b
d
1
e
Night Service Jack
Trunk
5
3
2
J
Ans.
R K
c
f
4
l_a
l_t
Office Signalling Key


D
Charging Trunk
Night Service Jack
Trunk
1
5
2
8
9
J'
f'
To 48-Volt, C-O. Battery

F


Office
erator
To Hand Generator
B.K
L K
h
j
m
g
i
R K
Call
B
Extension Line
a
Line Relay
4'
l1
lc
x
Other Line Lamps
Operator's Set
B K1
k
R
T
Extension Line Without Line Relay
A

lighted. When the operator answers the call by plugging in, the tip and ring springs will be lifted from the inside contacts of the jack, thus cutting off the lamp and battery connections. The line circuit shown at *B* differs from that at *A* only in that a relay is employed, the relay coil being placed directly in the line circuit and the lamp in a local circuit. Boards of this type are made convertible with respect to their line circuits, and the change from one type of circuit to the other can be made by simply connecting the lamp circuit with the tip contact of the

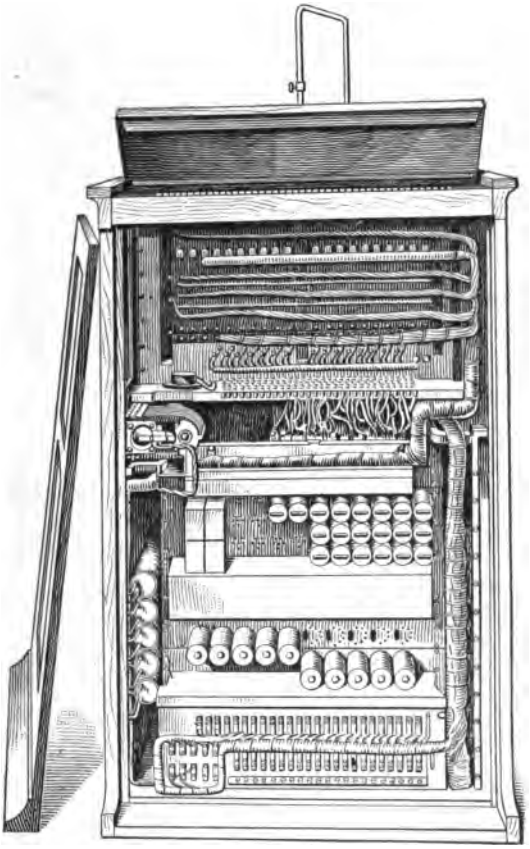


FIG. 2

jack, as indicated by the dotted line at *a*. The relay can then be removed, leaving the circuit as shown at *A*. In the use of these No. 4 switchboards, lamps are connected in circuit with

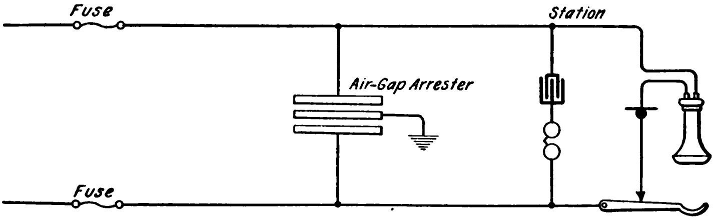


FIG. 4

lines of which the resistance is 100 ohms or less, exclusive of the instrument resistance. For all lines having a resistance greater than 100 ohms, the line relay is employed as shown at *B*.

TRUNK CIRCUITS

3. Two types of trunk circuits, indicated at *C* and *D*, Fig. 3, are employed in the non-multiple board. These trunks differ from each other in that one of them, the *regular trunk*, shown at *C*, is adapted to act merely as a private-branch-exchange trunk; the other, the *charging trunk*, shown at *D*, is adapted also to serve as a charging lead from the main-office battery at times when the trunk is not in use for talking. The regular trunk employs three relays and the charging trunk four. Each trunk employs a jack with a tip, ring, and sleeve contact and with a make-and-break contact, the purpose of which will be described later.

4. If cable conductors between the central office and the private-branch exchange are plentiful and neither the distance nor the load is too great, the preferred form is the regular trunk with separate conductors for a battery circuit. In such cases a storage battery is not used at the branch exchange, unless the exchange is so large as to make such a battery necessary. If charging trunks are used, a storage battery is always required at the branch exchange, so that current will be available when the trunks are in use for talking purposes. A 48-volt charge is taken from the central office for this system, and the storage battery at the branch consists of nineteen cells, giving a local pressure of about 41 volts.

CORD CIRCUITS

5. The cord circuit is of the complete double lamp supervision type, having a separate supervisory lamp for each plug, these lamps being controlled primarily by relays in the ring conductor of the cord. The peculiar feature about this cord circuit is that the operator's set is connected with battery only while the listening key *L K* is in listening position, and the supervisory lamps l_a and l_c can be connected with battery only while the listening key is in the normal position. There is thus no waste of electricity in the operator's set when it is not in use. Moreover, long-distance transmission is not weakened when the operator listens in, because her set does not take current from the through line.

OPERATION

CALL FROM CENTRAL OFFICE TO EXTENSION STATION

6. The regular trunk shown at *C*, Fig. 3, terminates at the central office, the same as does a subscriber's line. In order to signal the branch operator, the central-office operator inserts a calling plug into the trunk jack and operates her ringing key, thus setting up ringing current in the path including the ring side of the line, the lower contact of the night-service jack–the lower condenser in the trunk circuit–contact *b*–the coil of relay *1*–contact *c* of the trunk jack *J*–to ground. This alternating current operates relay *1*, which closes a contact *d*, and then opens contact *b*. Contact *d* closes a circuit from the battery to the ground through one of the windings of relay *2* in series with the winding of relay *1* and contact *c*. Relay *1* is thereby locked in its closed position. Contacts *b* and *d* are of the make-before-break type, so that the relay has no chance to let go while the connections are changing to the locking circuit. The condenser across the terminals of the winding on relay *1* minimizes its tendency to flutter. When this relay operates, contact *e* also closes, thus completing a circuit through the trunk signal lamp l_t, which therefore lights. The current in relay *2* causes it to operate and close two contacts, one of which short-circuits the impedance coil *3* and the other connects the sleeve of the trunk jack *J* to the ground through one winding of relay *2*. The purpose of these changes will appear later.

7. When the trunk-line signal lights, the branch operator inserts an answering plug into the jack *J* and thereby establishes connection between the two sides of the line and the tip and ring conductors of the cord, at the same time breaking the jack contact *c* and closing the jack contact *f*. Breaking the jack contact *c* opens the circuit of relay *1*, thus deenergizing that relay and putting out the trunk lamp l_t. Deenergizing relay *1* also opens the contact *d* of that relay and thus opens the circuit of the winding that caused relay *2* to operate. This relay is not deenergized, however, because its other winding is now in a circuit through the sleeve of trunk jack *J*–the sleeve contact of the answering plug–back contact of relay *4*–supervisory lamp l_a–contact *g* of the listening key *L K*–battery–ground.

8. Inserting the answering plug also connects relay *5* across the trunk circuit, the path being from the ring conductor of the trunk circuit through relay *5*–one pair of contacts of relay *2*, which is still energized–office signaling key–contact *f* of the trunk jack *J*–to the tip side of the trunk. The establishment of this low-resistance path across the trunk causes relay *5* to open its back contact, operates the supervisory relay at the central office to show the response of the branch exchange, and also trips the automatic ringing key in the central office.

In order to accomplish these functions at the central office, the coil of relay *5* must be of comparatively low resistance and impedance. If it were left permanently bridged across the talking circuit of the trunk in this way it would interfere with the talking efficiency. But the act of listening in on the line by the branch operator opens the energizing circuit of relay *2* at contact *g* and at the same time extinguishes the light of the supervisory lamp l_a. The armature of relay *2* falls back, and the impedance coil *3* is thereby connected in series with relay *5*. The impedance of the circuit through relay *5* is thereby made high enough to prevent bad effects on the talking efficiency.

9. If the listening key is then returned to its normal position, the supervisory lamp can be relighted by the central-office operator by simply withdrawing and immediately reinserting her calling plug, thus affording a means of recalling the attention of the branch operator. Withdrawing the calling plug deenergizes relay *5* and closes a circuit from the battery through a winding of relay *2*–back contact of relay *5*–tip side of trunk circuit–tip side of cord circuit–impedance coil *6*–ground. The contacts of relay *2* close the contacts on the right, thus closing the circuit through the other winding of relay *2* and the supervisory lamp l_a. After the calling plug at the central office has been reinserted, the circuit of the left-hand coil of relay *2* is opened at the back contact of relay *5*, and the branch operator can then extinguish the light l_a by listening in on the line again.

10. In short, relay *1* is the line relay by which the trunk signal lamp l_t is controlled. Relay *2* provides for locking relay *1* until an answering plug is inserted in the trunk jack, after which relay *2* acts to control the supervisory lamp l_a of the associated cord circuit. While the answering plug is in the jack, this supervisory lamp is under the exclusive control of the contact shown at the right of relay *2* and can be relighted by withdrawing the calling plug at the central office, as already explained. Supervisory relay *4* cannot be energized while the associated plug is in a trunk jack, because of the condenser in the ring side of the trunk circuit and the opening of contact *c* in the jack. Relay *5* not only serves to hold a closed path across the trunk while the trunk is in use, but also enables the central office to recall the branch operator through relay *2* and the supervisory lamp associated with the answering plug in use.

11. By inserting an answering plug in the jack and throwing her listening key, the branch operator not only extinguishes the supervisory lamp l_a, as previously explained, but she connects her set to the cord circuit by closing contacts at *h*, *i*, and *j*. On learning from the central office which subscriber is wanted, she releases her listening key, inserts the proper calling plug, and presses the ringing key associated with that plug. The supervisory lamp l_c lights when this plug is inserted, the circuit being from the battery through contact *k* of battery key $B\ K_1$–contact *m* of listening key *L K*–supervisory lamp l_c–back contact of relay *4*–sleeve contact of plug and sleeve of jack–to ground.

When the subscriber's receiver is lifted, lamp l_c goes out, because relay *4* is energized by current in the circuit from the battery through impedance coil *7*–contact of key *B K*–coil of relay *4′*–ring contacts–subscriber's line–tip contacts–key *B K*–impedance coil *6*–ground. The back contact of relay *4′* opens the circuit of the lamp l_c, but when the receiver is replaced on the hook this contact closes the circuit and the lamp relights. The branch operator is thereby advised that the conversation is finished or that further attention is desired.

During the conversation the extension line is connected with the battery through impedance coils *6* and *7*. The branch operator can call the central-office operator by pressing the office signaling key, thereby opening the circuit of relay *5*, flashing a lamp in the central office, and lighting supervisory lamp l_a in the branch exchange.

12. Night-Service Connections.—A battery key *B K* is associated with each cord so that all sources of current can be cut off from the talking conductors of each individual cord. This key not only interrupts the circuit through impedance coils *6* and *7*, but also severs all connection between the cord and the listening key and its associated battery connections. When the operator's battery key $B\ K_1$ is thrown, it severs all possible connection between the battery and the operator's set. One or more extension lines can be left connected with the central office during the night by means of the cords, using the night-service jacks and the battery keys thrown so that no electricity will be wasted from the branch-exchange battery. The cord circuits then make a through connection between the night-service jacks and the extension-line jacks, and all current supply is from the central-office battery.

CALLS FROM EXTENSION STATIONS

13. The connection changes thus far considered have been those made when a call comes from the central office. For a through connection in a reverse direction, the positions of the answering and calling plugs are interchanged, and this fact must be remembered in reading the following description.

When a receiver on an extension line is lifted, a circuit is completed from the battery at the branch exchange through the line relay–line circuit–to ground. The line relay closes the circuit of the line lamp l_l and the lamp glows. The branch operator inserts an answering plug in the extension-line jack, thereby opening the circuit of the line lamp l_l, throws her listening key $L' K$, learns that a trunk connection is desired, and inserts the calling plug in the trunk jack. The jack contact c is thereby opened, thus rendering relay *1* inoperative. A circuit is also completed from the battery through one of the windings of relay *2*–back contact of relay *5*–tip side of trunk-calling plug and cord-impedance coil *6*–to ground. Both contacts of relay *2* close, one connecting relay *5* across the trunk circuit, causing the line lamp in the central office to glow, and the other contact closing a circuit from the battery through contacts k of the battery key $B\,K_1$–contact m of the listening key $L\ K$–supervisory lamp l_c–sleeve contact of calling plug and sleeve of jack J–a winding of relay *2*–to ground. The branch operator can extinguish lamp l_c by throwing her listening key $L\ K$ so as to open the contact at m.

When the operator at the central office responds, the subscriber can obtain through her the desired connection. Talking current reaches the subscriber's line through impedance coils *6* and *7*, as before stated. When the subscriber's receiver is replaced on the hook, supervisory lamp l_a associated with the answering plug in that line jack glows, thus informing the branch operator that the connections can be taken down.

CHARGING TRUNKS

14. The charging trunk, shown at *D*, Fig. 3, has an additional relay *8* by means of which the trunk wires are made to act as charging leads when they are not in use for talking purposes. With this relay in its normal position, as indicated, a path for charging current exists from the 48-volt, central-office battery through the tip side of the trunk–back contact of relay *8*–adjustable resistance *9*–branch-exchange battery–ground. The polarities of the two batteries are so arranged that the branch-exchange battery is charged by this current. When a plug is inserted in the trunk *J'*, contact *f'* is closed, thereby completing a circuit through the coil of relay *8*, energizing this relay, opening its back contact, and discontinuing the charging current until the plug is removed. When relay *8* operates it closes a circuit across the trunk line through relay *5*, thus performing the same function as contact *f* in the jack of the regular trunk.

PILOT SIGNALS

15. As already stated, the circuits shown in Fig. 3 have been simplified by omitting the so-called auxiliary circuits that control the pilot lamps or the audible signals, or both. These auxiliary circuits are controlled by placing a relay in the common lead between the battery and the lamp signals. Thus, in line *B*, the circuit is shown from the battery to a single line lamp. This circuit branches to other line lamps, as indicated, and if at a point *x* in the common lead from the battery is connected a relay with a winding heavy enough to carry all of the current to as many of the lamps as would ever be operated at once, this relay will be operated whenever any line lamp is operated. Such a relay is called a pilot relay, and it may control an audible signal, such as a buzzer, or another lamp, known as a pilot lamp. The auxiliary circuits on the various sizes of No. 4 private-branch-exchange boards differ in some degree among themselves, but all operate on the principle and in the manner just described.

MULTIPLE BOARDS

16. When private branch exchanges become of such size as to require multiple rather than non-multiple boards, the general circuits described for the No. 4 board are modified by giving each extension line a number of jacks rather than a single one and providing a *busy test* to prevent more than one connection being made with a line at the same time. This test will be explained later. In multiple private-branch-exchange boards of this type, the trunk jacks also are multipled through the board, and are made of very much simpler form than the trunk jacks, shown in Fig. 3. In fact, they are the simplest form of three-contact jack, employing no cut-off springs whatever. The switching functions performed by the trunk jack in non-multiple boards just described are performed by a special relay, which operates in connection with the sleeve of the jack.

SUBSCRIBERS' STATION PROTECTION

NECESSITY FOR PROTECTION

17. According to the National Board of Fire Underwriters in the United States, circuits carrying potentials below 550 volts are classified as low-potential circuits, those carrying potentials ranging from 550 to 3,500 volts as high-potential circuits, and those carrying potentials above 3,500 volts as extra high-potential circuits. As the electromotive force of direct current used in telephone exchanges is usually only 24 volts and seldom over 48 volts, and of the ringing currents is usually not over 150 volts, all telephone circuits come well within the low-potential classification.

18. None of the currents used in the operation of a telephone exchange are capable of doing damage at the subscriber's station, although they may, in some cases, do damage in the central office. The necessity of protecting subscriber's station equipment from damage by excessive electrical currents arises, therefore, wholly from the danger of accidental crosses between the telephone wires and the higher-potential wires of other companies. *Foreign*, or *extraneous*, *currents* are thereby set up in the telephone wires, and unless adequate protective apparatus is installed, the telephone apparatus, the property of subscribers, and even the lives of telephone users may be endangered.

19. In the circuit between the subscriber's premises and the central office nearly all subscribers' lines are more or less exposed to accidental contact with electric-light or power circuits, or to lightning discharges, and in such cases are called *exposed lines*. Sometimes a telephone wire falls across a trolley wire at street crossings or accidentally comes in contact with an electric light or power wire where the two are in proximity. Such accidental crossings are particularly liable to happen in time of storms. To insure the subscriber's station equipment against damage from hazards of this nature, a means of automatically grounding and opening the circuit and drawing off the stray high-potential currents is provided, usually at the point where the wires enter the subscriber's building.

MEANS OF PROTECTION

20. The theory of substation protection is illustrated in Fig. 4, which shows the line wires leading through fuses to a subscriber's station at the right with an air-gap arrester connected to the lines between the fuses and the telephone. The arrester consists of three carbon plates separated by layers of mica usually about .005 inch thick, and part of this mica is usually cut away so that parts of the plates are separated only by thin air gaps. The middle plate is connected to the ground and each outside plate to a line. If the voltage across the lines rises to a dangerous value, the arrester will discharge; that is, electricity will jump the air gaps and escape to the ground. As a rule, the telephone apparatus is constructed to withstand at least 500 volts with safety, but the arrester usually discharges at less than that voltage.

In order to prevent the continuation of arcs between the plates when discharges occur, a small drop of solder is sometimes included in one of the carbon plates of each air gap, the idea being that this solder will melt, join the two plates, and provide a low-resistance path that will extinguish the arc before its heat can set fire to the surroundings.

21. In any case, whether or not solder is used as described, the path to the ground might carry a current large enough to overheat the arrester and the conductors leading to it, except for the fuses mounted near the arrester. These fuses are proportioned to carry safely any of the normal currents used in telephone work, but to melt, or blow, when the current rises to a dangerously high value, thus opening the circuit and protecting the apparatus.

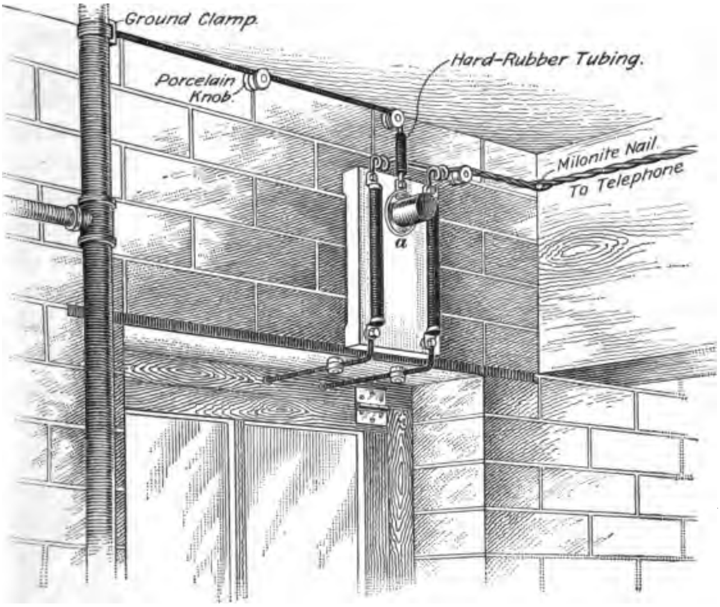


FIG. 5

The fuse employed for substation protection consists of a thin ribbon of lead about 4 inches long, connected between two brass terminals. These terminals are mounted in the opposite ends of a fiber tube, which forms a mechanical protection of the delicate fuse and also prevents the scattering of melted metal or hot gases when the fuse is blown.

22. The method of mounting a protector, including an air-gap arrester and two fuses, in the cellar of a residence is shown in Fig. 5. The line wires are brought in through a window casing in separate tubes and clamped under the fuse terminals. From the other ends of these fuses the circuit continues through a twisted pair to the telephone. To the same fuse ends to which the telephone circuit is joined are connected the terminals of the air-gap arrester *a*; the ground terminal of the arrester is connected with a convenient water pipe. *The fuses must always be on the line side of the arrester rather than on the instrument side,* so that the grounded current through the arrester must also pass through the fuses.

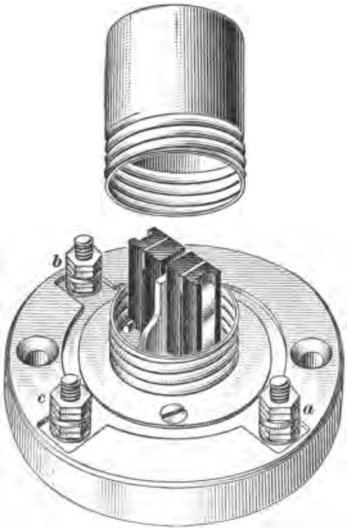


FIG. 6

23. The appearance of the interior of an air-gap arrester is shown in Fig. 6. Terminals *a* and *b* are for line connections, and terminal *c* is for the ground connection. The carbon blocks can be easily withdrawn from between the spring blades holding them, and between each pair of blocks is a strip of mica notched as indicated in Fig. 7. The inner block of each pair is in connection with the ground wire, and each outer block in connection with a line.

24. **Instructions for Installing Protectors.**—The protector at a subscriber's station should be placed within the building as near the entrance of the line wires as possible, due allowance being made for an easily accessible ground connection and for convenience in inspection and repair. It should be at least 6 inches from probable contact with curtains, shades, or other inflammable material. It should be securely fastened to a firm support; the fuses should be vertical, and should be so placed as to allow the line wires to be attached directly to the binding posts. The protector may be mounted so that these posts are either at the top or the bottom, but the micas should always be placed with the notched side down. A protector should never be placed in a show window, on damp walls, or on vibrating partitions.

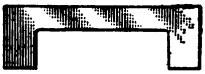


FIG. 7

INSTALLING TELEPHONE APPARATUS

INTERIOR WIRING

WIRE GAUGES

25. By **interior wiring** is here meant the wiring between the protector block near the point where the line wires enter a subscriber's building and his telephone or group of telephones. A **wire gauge** is an instrument for measuring the diameters of wires. One form of wire gauge, shown in Fig. 8, consists of a circular steel plate with notches in the edge, the width of each notch being just sufficient to allow wire of a given diameter to pass through it. A still more accurate device for measuring wire diameters is the micrometer, which is shown in Fig. 9.

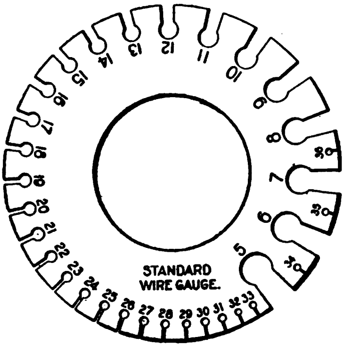


FIG. 8

26. The name *wire gauge* is also used in referring to series of numbers that indicate wires of standard diameters. Several such gauges are in general use, the three most common being the *Standard*, or *Brown & Sharpe* (abbreviated B. & S.), the *New British Standard* (N. B. S.) also known as the *English Legal Standard* (E. L. S.), and the *Birmingham Wire Gauge* (B. W. G.). Copper wire, especially in small sizes, is nearly always specified by the Standard, or Brown & Sharpe, gauge, and this is the only gauge that will be considered at present. The Birmingham gauge is generally used to specify sizes of iron wire.

27. In the Brown & Sharpe gauge, the sizes generally listed range from the largest, No. 0000 (read *four naught*), through the successive sizes 000, 00, 0, 1, 2, etc. down to the smallest size, No. 40. No. 0000 B. & S. wire has a diameter of 460 *mils*, or .460 inch, 1 mil being $\frac{1}{1000}$ inch. The diameters decrease as the gauge numbers increase, No. 40 wire being only 3.145 mils, or .003145 inch, in diameter. The sizes, weights, and resistances of soft copper wire, according to the Brown & Sharpe gauge, are given in Table I. As other gauges differ, the wire gauge, as well as the number, must be specified in order to designate a particular size of wire.

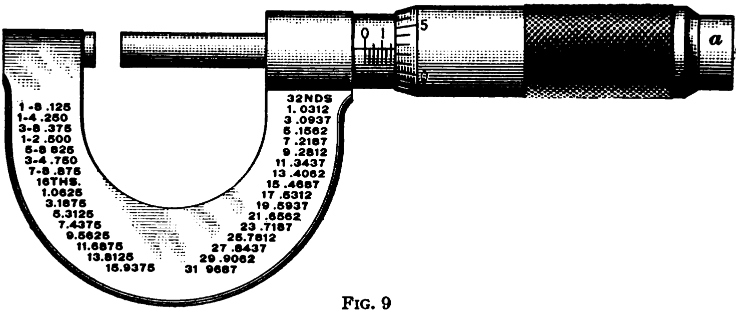


FIG. 9

28. The sectional areas of wires are usually expressed in circular mils, which are simply the squares of their respective diameters in mils. For example, the diameter of No. 0000 B. & S. wire is 460 mils and its sectional area is 460×460=211,600 circular mils. Sectional areas need rarely be considered by those who are installing and operating telephones, but these areas are given in Table I for reference if needed. In the B. & S. wire gauge each change of three gauge numbers approximately doubles or halves the sectional area and consequently halves

TABLE I

COPPER WIRE—B. & S. GAUGE

Wire Gauge Number	Diameter of Wire Mils d ($\frac{1}{1000}$ inch)	Circular Mils d^2	Weight Pounds per 1,000 Feet	Resistance Ohms per 1000 Feet	
				Annealed Copper	Hard-Drawn Copper
0000	460.0	211,600	641	.0490	.0493
000	409.6	167,800	508	.0618	.0622
00	364.8	133,100	403	.0779	.0785
0	324.9	105,500	319	.0983	.0989
1	289.3	83,690	253	.124	.125
2	257.6	66,370	201	.156	.156
3	229.4	52,630	159	.197	.198
4	204.3	41,740	126	.249	.250
5	181.9	33,100	100	.313	.315
6	162.0	26,250	79.5	.395	.398
7	144.3	20,820	63.0	.498	.501
8	128.5	16,510	50.0	.628	.632
9	114.4	13,090	39.6	.792	.797
10	101.9	10,380	31.4	.999	1.01
11	90.74	8,234	24.9	1.26	1.27
12	80.81	6,530	19.8	1.59	1.60
13	71.96	5,178	15.7	2.00	2.02
14	64.08	4,107	12.4	2.53	2.54
15	57.07	3,257	9.86	3.18	3.21
16	50.82	2,583	7.82	4.02	4.04
17	45.26	2,048	6.20	5.06	5.10
18	40.30	1,624	4.92	6.39	6.43
19	35.89	1,288	3.90	8.05	8.11
20	31.96	1,022	3.09	10.2	10.25
21	28.46	810.1	2.45	12.8	12.9
22	25.35	642.4	1.94	16.1	16.2
23	22.57	509.5	1.54	20.4	20.5
24	20.10	404.0	1.22	25.7	25.8
25	17.90	320.4	.970	32.4	32.6
26	15.94	254.1	.769	40.8	41.1
27	14.20	201.5	.610	51.5	51.8
28	12.64	159.8	.484	64.9	65.3
29	11.26	126.7	.384	81.8	83.0
30	10.03	100.5	.304	103	104
31	8.928	79.70	.241	130	131
32	7.950	63.21	.191	164	165
33	7.080	50.13	.152	207	208
34	6.305	39.75	.120	261	263
35	5.615	31.52	.0954	329	331
36	5.000	25.00	.0757	415	418
37	4.453	19.83	.0600	523	527
38	3.965	15.72	.0476	660	664
39	3.531	12.47	.0377	832	837
40	3.145	9.888	.0299	1,049	1,060

or doubles the resistance. Each change of one number makes a change of approximately 26 per cent. in the sectional area and an inverse change of the same percentage in the resistance. For example, No. 10 wire, B. & S. gauge, has a resistance of approximately 1 ohm per 1,000 feet; the resistance of No. 13 wire, three sizes smaller, is approximately 2 ohms, No. 16 wire 4 ohms, No. 17 wire 1.26×4 = 5.04 ohms, No. 7 wire, three sizes larger than No. 10, .5 ohm, etc. These figures are not accurate, but this method is often convenient for estimating purposes.

COPPER WIRE

29. All copper wire for electrical purposes, except that for use where great tensile strength is required, should be *annealed*, or *soft-drawn*. For practically all telephone purposes it should also be insulated, except for stringing on poles, where bare wire may be used. The principal materials used for insulating wire are wrappings or braidings of cotton or silk, various kinds of enamel, which are baked on the wire, and various compounds of rubber, which are molded on the wire in a plastic condition and afterwards baked or vulcanized.

Wire on which one, two, or three layers of cotton or silk are braided is commonly referred to as *magnet wire*, because of its use in the windings of magnets. Wire coated with insulating enamel, baked on, has also come into wide use for winding magnets.

Frequently copper wire that is to be insulated is coated with tin by passing it through a bath of molten tin before the insulation is applied. This accomplishes two desirable purposes; namely, it facilitates the use of solder in splicing two wires together, or in attaching them to metal terminals, and it prevents the chemical ingredients of the insulation, particularly where rubber is used, from corroding the copper.

Copper wire that is covered with one or two wrappings of cotton, afterwards soaked in paraffin, is called **annunciator wire.** Except in a few special cases, some of which will be mentioned later, such wire should never be used in interior wiring, on account of its liability to absorb moisture.

30. The standard inside wire adopted by nearly all telephone companies for inside wiring where protected from exposure to the weather or excessive moisture, is either No. 18 or No. 19 B. & S. gauge. It is first covered with a rubber compound, and outside of this with a braiding of cotton. This cotton is in various colors, so that a color can be selected to match the woodwork of the rooms in which it is installed. Such wire is made in single, double, and triple strand, known, respectively, as single, duplex, and triplex wire.

31. The standard outside wire used wherever there is exposure to moisture, including the outside of buildings, is insulated similarly to inside wire, except that the cotton braid is saturated with a black insulating compound. Outside wire can be used for inside wiring in two general cases: (1) in unusually damp places, and (2) for running direct to telephones located within 15 feet of the entry of buildings. This practice can be followed in some cases, provided the outside wire does not present an unsightly appearance when used inside.

INSTALLATION OF CONDUCTORS

GENERAL METHOD OF RUNNING WIRES

32. Inside wire should be run in inconspicuous places and should avoid finely finished walls and woodwork, pipes, and electric-light and power circuits. The wire should preferably follow the picture molding. If no molding is available, the wire should be fastened to the baseboard in a way to avoid damaging the woodwork. Chair rails and other places where the wire would be directly exposed to damage should be avoided.

In boring through walls and frames, extreme care should be exercised to avoid interference with sliding doors and windows; also not to apply too much pressure as the point of the bit approaches the opposite surface, as otherwise the bit will be pushed through and will damage the surface. The safest plan usually is to bore through the baseboard or molding in preference to plastered walls.

33. When the telephone instrument is located on a desk or other fixture, away from the wall, the wire should be extended under the floor, if possible. If the wire is laid on top of the floor, it should be covered with molding so as to avoid damage to the wire, or to the subscriber's property, or the possibility of accidents from tripping.

When the telephone is located on a desk or other piece of furniture that must be moved occasionally, the wiring and apparatus must be arranged to permit such movements without the services of the installer or inspector of the telephone company, and without interrupting the service of the instrument. For this purpose, about 3 feet of slack wire, coiled neatly to clear the floor, should be left under the desk or table so as to permit the movements without straining or breaking the wires. Wire extensions under carpets from the baseboard to a desk may be run with No. 18 single annunciator wire, the wires being separated at least 3 inches from each other. This is one of the few places in which annunciator wire may be used. The splice between the annunciator wire and the standard inside wire should be made at the baseboard.

No holes should be cut through carpets or rugs; the threads can nearly always be separated with a lead pencil or any pointed tool enough to let the wires through. Permission should always be obtained in writing from some one in authority on the premises before doing work of this character.

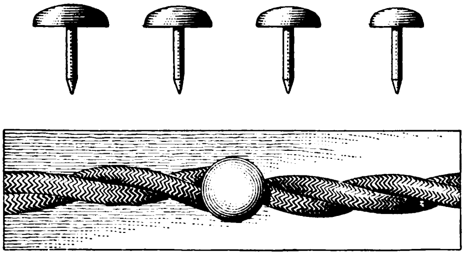


Fig. 10

FASTENING INSIDE WIRES

34. Inside wires should be secured to the wall preferably by means of *milonite nails*, as shown in Fig. 10. These are sometimes called furniture nails; they consist of metal shanks with heads of special insulating compound furnished in various colors. Milonite nails of two lengths, $\frac{1}{2}$ inch and $\frac{7}{8}$ inch, should be used for securing wires to woodwork and plaster walls, except where other methods of fastening by means of cleats, double-pointed tacks, tie-wires, clamps, or rings are necessary. The shorter nails should be used in hard wood and the longer nails in soft wood and plaster. Two pairs of wires may be secured with one nail, as shown in Fig. 11. Nails and tacks should not be used on metal walls, around window sills, in damp places, or on outside wiring.

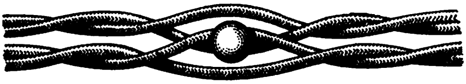
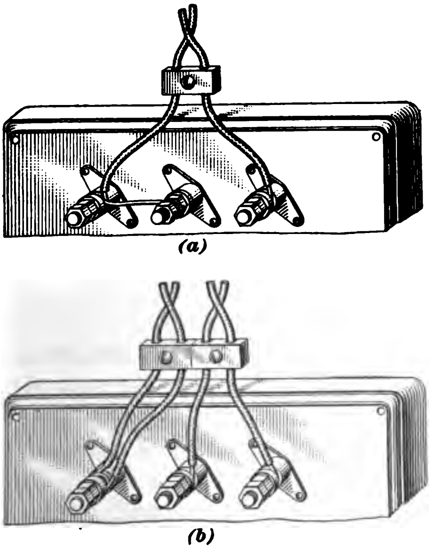


Fig. 11

If the wires are in channels or grooves in woodwork, the nails should be spaced about 18 inches apart; otherwise, they should be not more than 12 inches apart. In rounding inside corners, two nails should be used, placed about ½ inch on either side of the corner, and the wire should be bent back into the corner. In some cases insulated double-point tacks are more satisfactory than milonite nails for securing single wire to walls and also for securing one strand of twisted pair wire. *In no case should both wires of a twisted pair be secured under the same double-point tack.*

Two-wire or three-wire cleats may be used for securing the wires to metal or plaster walls and around window sills. These cleats should always be secured to the wall by means of wood screws. A cleat should always be used for securing the wires near the point of attachment to the binding posts of the instrument or terminal block, as shown in Fig. 12.



(a)

(b)

Fig. 12

Sometimes a group of wires run along a ceiling or wall may be supported by tie-wires, as shown in Fig. 13 (*a*). Annealed-iron tie-wires and cut nails should be used for this purpose. The tie-wires are twisted around the conductors as shown in view (*a*), and methods of securing the tie-wires to the wall are shown in views (*b*) and (*c*). The conductors should always be served with a wrapping of adhesive tape at the point of support.

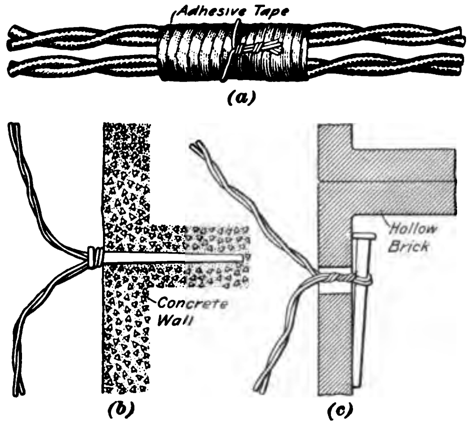


FIG. 13

SPLICING INSIDE WIRES

35. Inside wires may be spliced either by a twist joint or by copper sleeves. The various steps in making a twist-joint splice, also called the *Western Union joint*, in a wire are shown in Fig. 14. The insulation is removed from each wire for about 4 inches from the ends of the wires, extreme care being taken not to nick the wires. The wire ends are then scraped clean, and when crossed have the appearance shown in view (*a*). Each end of the wire is then twisted closely four times around the bare surface of the other and then four times around the insulation on the other. The ends of the wire are then cut close and pressed in, giving the appearance shown in view (*b*). The length of bare wire exposed between the ends of the insulation should not be more than 1 inch. The joint is then soldered by holding the iron underneath the splice and applying a stick of rosin solder just above the splice for a very short time. The splice should then be struck a sharp blow to shake off the excess of solder. Only rosin-core solder, consisting of a tube of solder filled with powdered rosin, should be used; this solder carries with it the proper amount of flux. No acid or prepared soldering pastes should be used, as these are likely to cause corrosion.

After the joint is soldered, it should be covered with two reverse layers of adhesive tape, starting at a point 1 inch back of the insulation on one of the wires and continuing for the same distance on the other side. The finished joint should be as shown in view (*c*). All splices in duplex or triplex wire should be separated by a distance of 6 inches, as shown in view (*d*).

36. Joining copper wires by means of copper sleeves forms what is often called the McIntyre joint. The sleeves consist essentially of two hollow copper tubes, joined together side by side, or rolled together from one piece of stock so as to have the cross-section shown in Fig. 15 (*a*). In making the joint the insulation is removed from the ends of the wires for about 4 inches, care being taken not to nick or bruise the wire or injure the insulation beyond the point of removal. The wires are then scraped clean and are inserted in the sleeve from opposite directions, being pushed through so that the insulation touches the sleeve on each end, as shown in (*b*). The sleeve is then held with a pair of pliers at one end and twisted with a

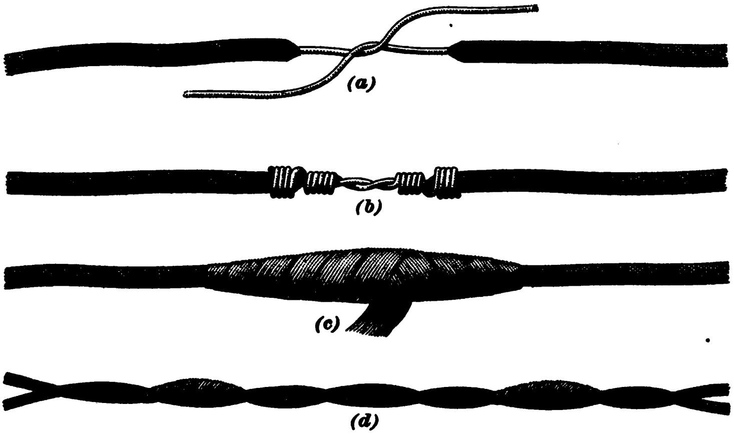


FIG. 14

pocket connector applied to the other end, giving the appearance shown in (*c*). The wire ends are wrapped about the insulation in the same manner as was done with the twisted

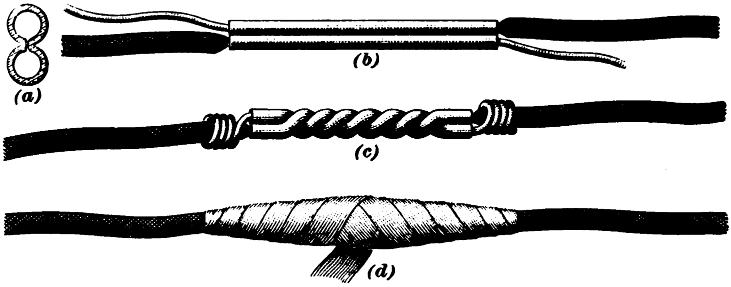


FIG. 15

splice, and the entire splice is wrapped with two reverse layers of fiber tape, as shown in (*d*). The joints in duplex and triplex wire should be staggered as in the ordinary twisted joint.

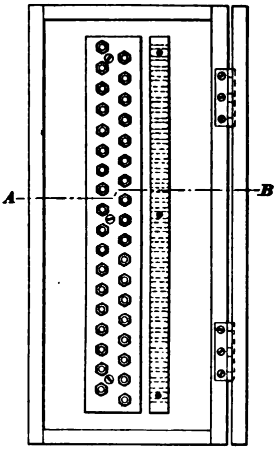
WIRING LARGE BUILDINGS

37. The extensive use of the telephone at the present time in hotels, apartment houses, and office buildings makes essential some provision in all modern buildings of these types for carrying the large number of wires necessary for telephone service. A single building may contain hundreds of telephones, and two wires must run from each telephone to some central point in the building. Provision should be made in the building plan for this mass of wires; otherwise, they must be run open on the walls and ceilings or expensive alterations must be made in the building after it is completed. While the general manner of wiring buildings of the same class will be similar, the particular requirements may differ considerably on account of special conditions.

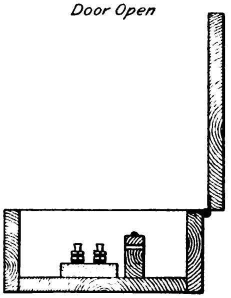
38. Considered with reference to wiring for telephone service, buildings may be divided into two general classes, the first of which includes hotels and apartment houses, and the second office buildings. In a hotel or apartment house the maximum number of telephones in any one room or on any floor is definitely fixed, being almost invariably one per room in a hotel, and one per apartment in an apartment house. The whole building may thus be permanently wired with the almost certain knowledge that there will be no change in the number of wires required. In these buildings it is also comparatively easy to designate a permanent location for the telephone.

In an office building, on the other hand, the number of telephones depends largely on the character of the business district in which the building is located; neither the number of telephones nor their locations in such a building remains fixed, but changes with the changing requirements of tenants. An office building, therefore, requires a more comprehensive and flexible system than an apartment house or hotel.

39. Wiring of Hotels and Apartment Houses.—In a large hotel or apartment house, a telephone in each room or apartment is connected by two wires with a common center near a switchboard. One or more pairs of trunk wires, usually in 2-inch conduit, run from the switchboard to the point at which the telephone cable enters the building, generally in the basement. In a hotel, the switchboard is commonly in or near the office.



Front Elevation with Door Open



Section on A B.

FIG. 16

40. One of the simplest and cheapest methods of wiring new buildings of this type is as follows: On each floor should be mounted one or more terminal boxes such as shown in Fig. 16. The number of such boxes needed depends on the floor area, and their locations should be convenient to vertical pipe shafts.

From each terminal box a conduit is run to a designated location in the wall of each room in which a telephone is to be placed. The height of the outlets in each room should be 4 feet 10 inches from the finished floor, this having been found to be the most satisfactory height to place the telephone. A ½-inch conduit will carry three twisted pairs, a ¾-inch conduit seven pairs, and a 1-inch conduit twelve pairs, but only one, three, and five pairs, respectively, are generally drawn into these conduits. In general, the longer the run the greater the number of pairs employed and the larger must the conduit be.

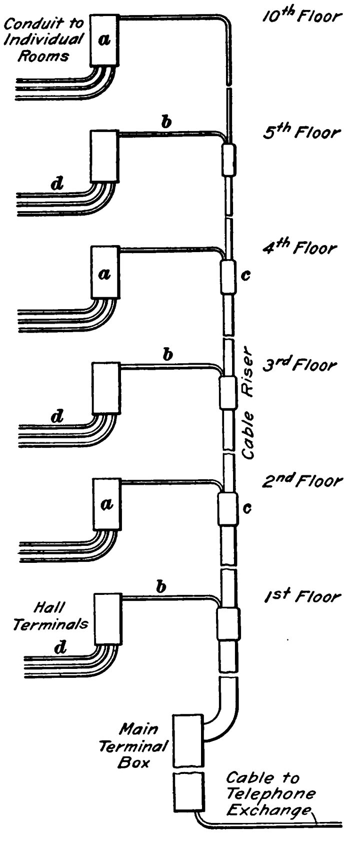


FIG. 17

This general scheme of riser cables and terminal boxes is shown in Fig. 17. From the central point, or main terminal box, near the switchboard, a cable is run through the vertical shaft near the hall terminal boxes *a*. The size of this cable diminishes at each box, because a tap cable *b* of sufficient size to provide wires for all telephones on that floor is there terminated. These tap cables are spliced into the riser cable at points *c*. In very large buildings several such riser cables may be in use. Conduits *d* lead from the hall terminal boxes to the telephones.

41. The general layout of connections in the main terminal box is shown in Fig. 18 and the details of making connections in all the terminal boxes in Fig. 19. The wires to be joined are clamped together under nuts on a *terminal*, or *locknut, strip.*

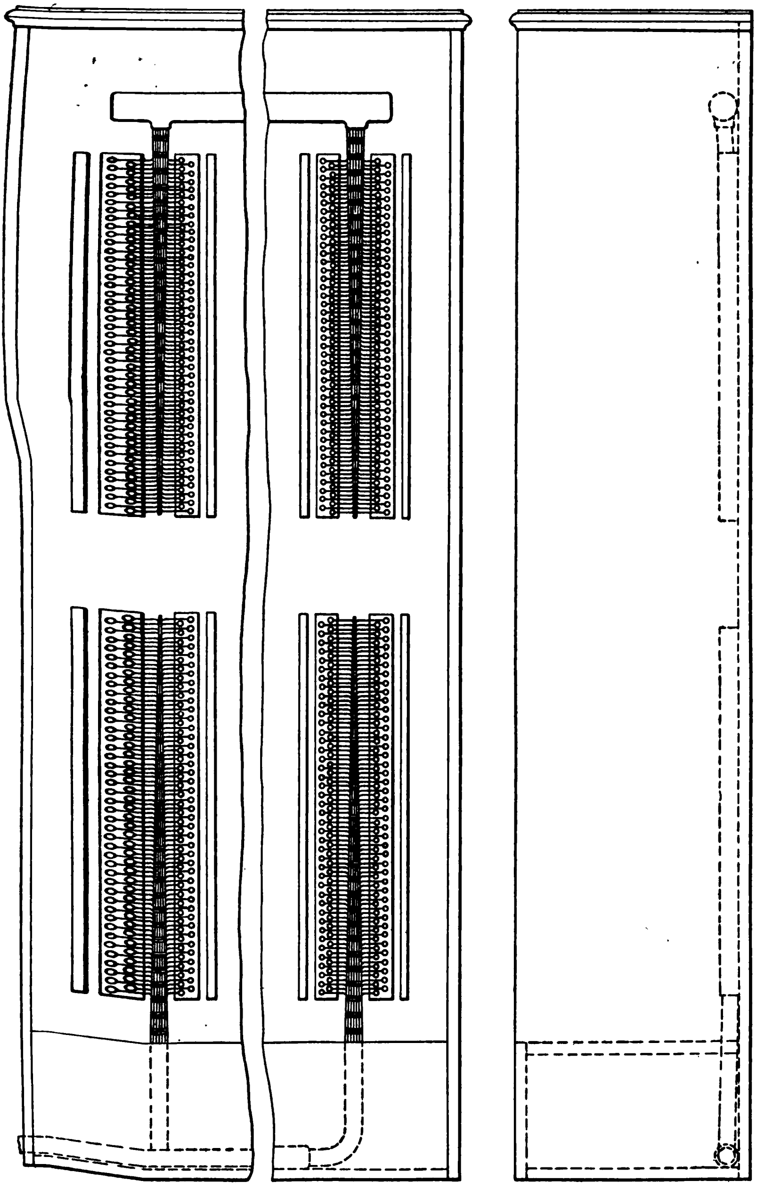


FIG. 18

The wires extending to instruments, etc. pass under a *form strip*, or *fanning strip*, with numbers and names to indicate the destination of each circuit. In Fig. 18 is indicated the arrangement of locknut strips and form strips for connecting 420 pairs of wires. A floor plan of an installation such as just described is shown in Fig. 20; the key accompanying the illustration makes it self-explanatory.

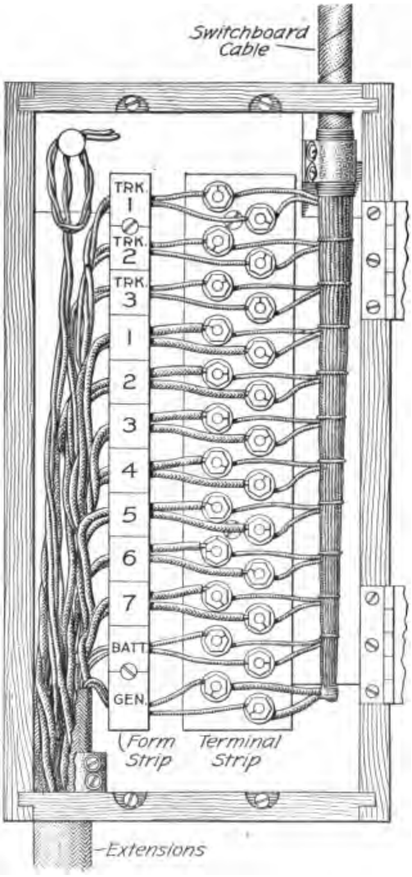
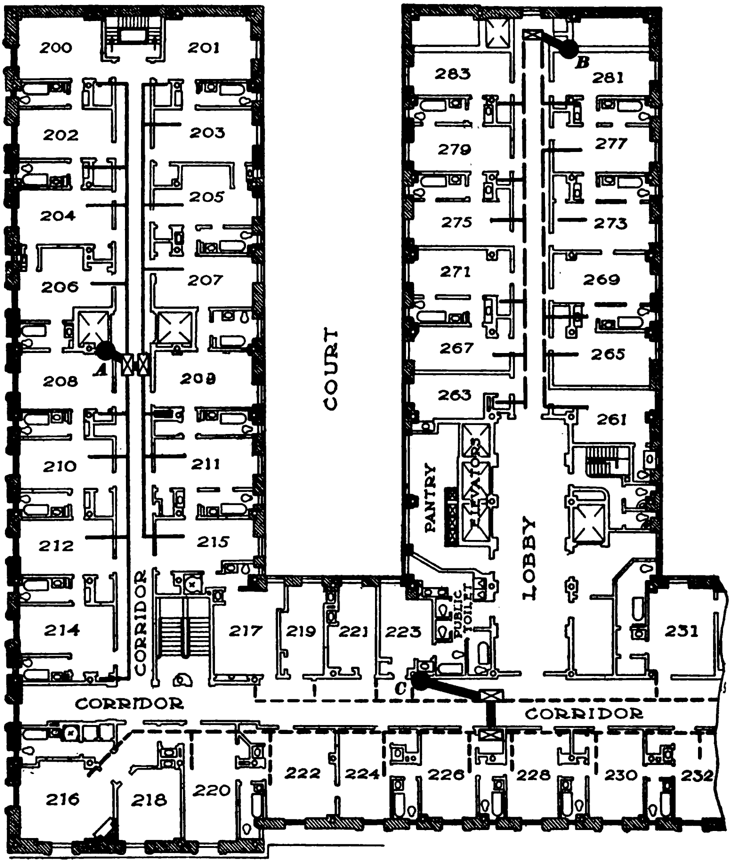


Fig. 19

42. In apartment houses, where only one telephone for each apartment is required, a simple method of wiring is to carry a vertical conduit up through each tier of apartments, and provide an outlet in each apartment. Individual pairs of twisted rubber-covered wire can then be pulled through this conduit for each telephone. The individual wires can be carried in a cable from the bottom of the risers to the switchboard location. With this system the telephone location must be about the same in each apartment supplied from the same riser. Floor plans for a building wired in this manner are shown in Fig. 21.

43. Wiring of Office Buildings.—In large office buildings the service cables from the telephone exchange are usually terminated at some convenient place in the basement. Wiring



Key

● Cable riser

⊠ Hall terminal box.

▬ Cable run.

—— Wire run from cable riser *A*.

— — Wire run from cable riser *B*.

- - - - Wire run from cable riser *C*.

Fig. 20

the building for telephone service, therefore, consists in carrying wires from each floor to this point, the number of wires depending largely on the size of the building and the class of business for which it is to be used.

One or more terminal boxes, depending on the requirements, are provided on each floor at points adjacent to vertical pipe shafts up which one or more cables are extended from the basement. Elevator shafts can frequently be used for this purpose. From these cables branch taps of sufficient size to provide for service on each floor lead to the terminal boxes. These riser cables and the service cables from the telephone exchange should terminate in a common main terminal like that of Fig. 18, located in the basement, so that connections can be made easily between the two sets of cables. On account of the constant shifting of the number and location of telephones to

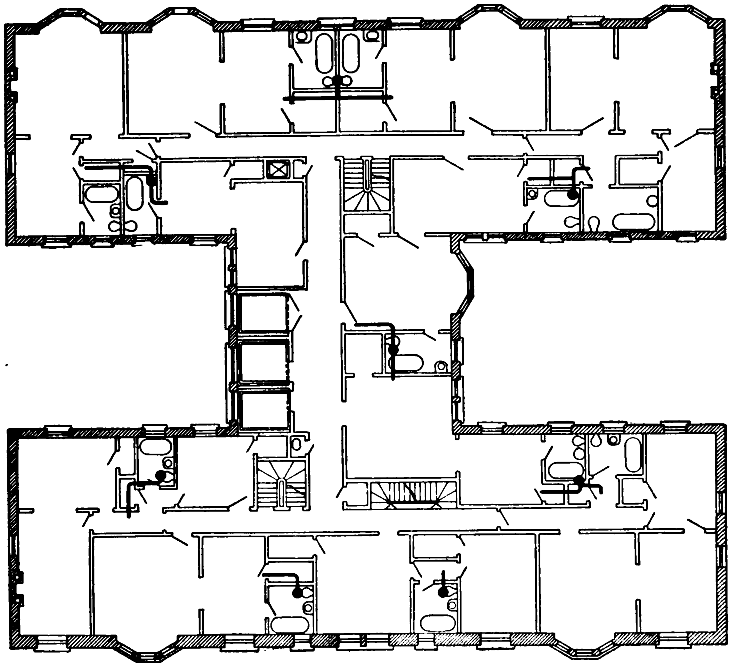


FIG. 21

meet the requirements of tenants, permanent wiring from the terminal boxes to the individual rooms is impracticable.

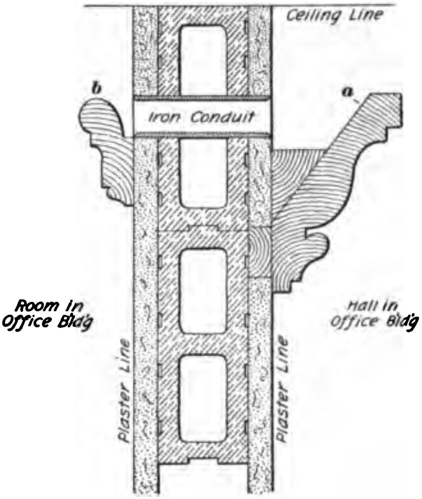
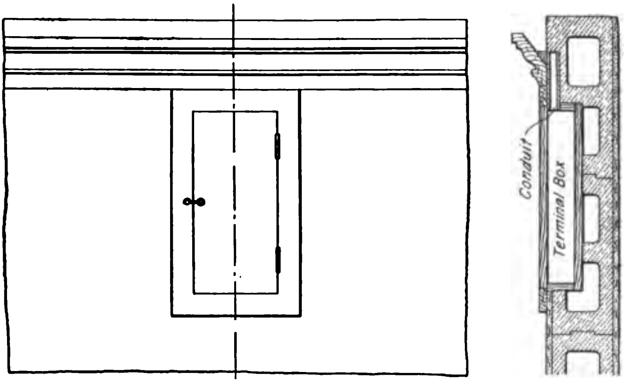


FIG. 22

44. The terminal boxes should be placed near the ceiling, and wide-shell molding, as shown at *a* in Fig. 22, should be provided in the halls for carrying the wires from the terminal boxes to the rooms. A smaller molding, shown at *b*, should be provided in the individual rooms for carrying the wires to the telephones. A sketch of a hall terminal box in position is shown in Fig. 23; view (*a*) shows the front, and view (*b*) a vertical cross-section through the center of the box, as indicated by the dotted line in view (*a*).

If the wires enter the room from a hall, a piece of $\frac{3}{4}$-inch conduit should be furnished for carrying them through the partition, as shown in Fig. 22, so as to avoid the necessity



(*a*) (*b*)

FIG. 23

for drilling holes after the building is completed. The conduit should either be lined with insulating material or the sharp edges around the ends of the pipe should be rounded off.

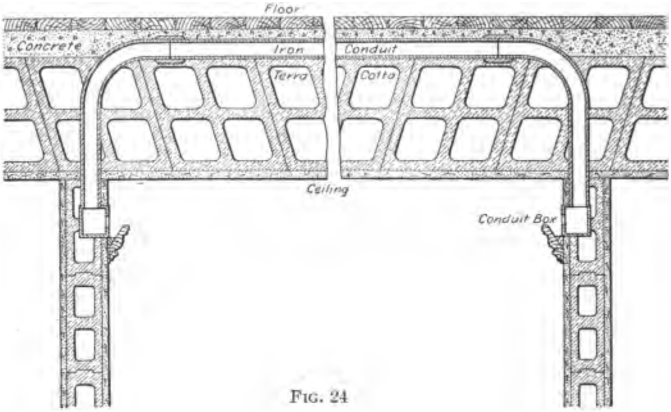


FIG. 24

Sometimes the floor terminals must be so placed that certain rooms cannot be reached without crossing other rooms. Provision should be made for such cases by installing conduit across the ceiling, as shown in Fig. 24, before the room is

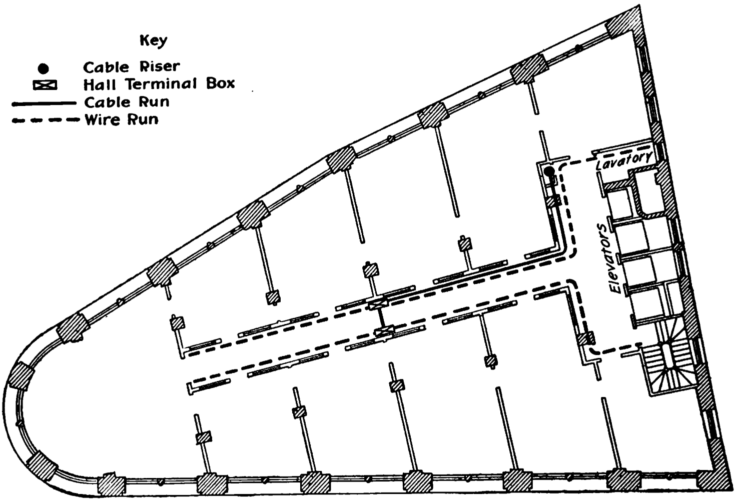


FIG. 25

finished. Wires can be drawn in later, and thus no exposed wires or circuitous routes around the walls of the room will be necessary.

The system just described calls for no conduit except in the comparatively rare cases where walls must be penetrated or remote rooms reached. The wiring is permanent only as far as the floor terminals, and changes in the distribution beyond these terminals can be readily made. Floor plans of a building showing this scheme of wiring are shown in Fig. 25.

INSTALLATION OF TELEPHONES

LOCATION

45. In all cases, the wishes of the subscriber should govern the exact location of the telephone, provided the following conditions can be fulfilled satisfactorily. The subscriber should be assisted in selecting a good location, and the selection should, in any case, be a matter of agreement. All telephones should be placed at points that will allow as direct wiring as possible to the arrester and that will not expose the instrument to damage by moisture or mechanical injury. Vibrating partitions and noisy locations should be avoided as far as possible. A telephone should not be within 2 feet of a window that is liable to be opened, if possible to avoid it.

FASTENING TELEPHONES TO WALL

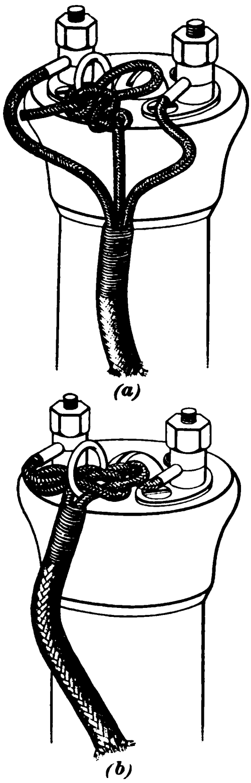
46. Wall sets and the bell boxes of desk sets should be securely fastened to the wall or partition on which they are to be mounted. In case of wooden or plaster-on-lath partitions, the fastening should be by means of round-headed wood screws of sufficient length to pass through the back board of the telephone or bell box and into the wall a sufficient distance to afford a secure hold.

In the case of brick, cement, or stone walls, holes should be drilled at the proper position for the screws. These holes should then be plugged with wooden plugs and the wall set fastened with round-headed wood screws. Care should be taken that thoroughly dry wood is used and that the plugs are large enough to hold securely. Instead of wooden plugs, expansion bolts may be used, if desired. The fastening to hollow tile walls is best made by drilling holes through the tile and using toggle bolts.

The telephone should be blocked out from an irregular or uneven wall with wooden blocks securely fastened to the wall with nails or screws, or with toggle or expansion bolts, in the manner just described for fastening the telephone directly to the wall.

ATTACHING RECEIVER CORD

47. The cord must be attached to the receiver in such manner that no strain will come on the terminals at the binding posts even if the receiver is dropped. If a tie string or strain cord is provided, it should be tied into the screw eye as shown in Fig. 26 (*a*). If there is no tie-string on the cord, the cord conductors themselves are tied into the screw eye as shown in (*b*).


(a)

(b)

Fig. 26

INSTRUCTIONS TO INSTALLERS

PLANT RECORDS

48. Large telephone companies almost invariably issue to their installers and other employes carefully prepared handbooks giving detailed instructions for carrying out the work. The instructions issued by each company conform to the particular requirements of the organization and its standards of construction, but in all cases the general aim is to secure both efficient work in accordance with proper standards and complete records of the work for the guidance of the company in the future maintenance and operation of the property.

49. The records of the telephone company's plant, or ***plant records***, as they are called, are of very great importance, as they enable the company to keep track of its property. Telephone wires are carried largely in cables, which may be either underground or overhead. On the maps and other records of the company, these cables themselves are numbered, as are also the pairs of wires in them. Certain of the cable pairs, always designated by number, are brought out to cable terminals, located in various parts of the city or town, so that these cable conductors are made available for connection with subscribers in that vicinity. All of this information concerning the location of cables, the numbers of the conductors they contain, and the points at which these conductors are brought out and made available for connection is shown on the company's cable records.

50. These records should also show just what subscriber or subscribers are connected to any cable pair, where each connection is made, and what kind of equipment is placed at each subscriber's station; that is, whether a wall set or a desk set, whether of direct or party-line type, and, if more than one, how many. In addition to installing the apparatus, a very important part of the installer's duties is to keep a systematic record of what he does, in the manner and in accordance with the routine prescribed by the company. In order to systematize this keeping of plant records, the installer receives his instructions in the form of a written order, issued from the office of the company, containing certain information and instructions as to what he is to do and also containing certain blank spaces to be filled in by him so that when the order is turned back to the office it will constitute a complete record of the installation.

These orders should be kept by the installer in a folder provided for the purpose. It is well for the beginner in telephone work to remember that *the condition in which he turns his orders back to the office is the most direct evidence he can give of his general fitness for the job.* They should be neat, clean as possible, and should have all blanks filled as far as the information can be obtained.

GENERAL DEPORTMENT

51. The installer must remember that the company for which he is working will be judged, in some degree, by the deportment of its employes. Public-service corporations, such as telephone companies, are paying more and more attention to matters of courtesy and civil treatment accorded to their patrons. An installer, on entering a residence or a private office, should keep in mind that he is working on the premises of others, and should make it a point to cause as little inconvenience or annoyance as possible. Such breaches of courtesy as failure to remove one's hat, chewing tobacco, or whistling or singing loudly while engaged in work in a private residence or office have caused more than one installer to lose his job.

It is particularly important that workmen in residences should avoid marring or soiling the walls or furniture or leaving the premises in a disorderly condition. When boring through plaster or woodwork, a newspaper spread on the floor or furniture to catch the dust or shavings will not only save work in the matter of cleaning up, but will do much toward making a good impression.

CHECKING CONDUCTOR ASSIGNMENTS

52. The following suggestions will give a general idea of what some of the larger telephone companies require in the matter of routine work with respect to installing a subscriber's equipment. The order issued to the installer contains, in addition to other information, the number of the cable pair and of the cable and the location of the terminal to which he is to make the connection. Before starting work on the actual installation, the installer should test the conductors of the pair assigned, at the terminal, in order to learn whether they are free from trouble and properly connected or cut in at the central office. If it is a magneto exchange, he makes this test by connecting a magneto test set, or portable magneto instrument, across the terminals of the pair and ringing the central office. If the call is received and he is able to talk over the line, he knows that the pair is in proper condition. If the exchange operates on the common-battery principle, he has only to bridge a portable test set, consisting of a transmitter and receiver, across the line, thus establishing a circuit between the two conductors of the pair and automatically signaling the central office. In this case, if he gets the proper response and is enabled to talk, he knows that the conductors assigned are in proper condition.

If the pair specified on the order is not found to be in working condition or is not available, the installer should, if possible, get another pair assigned, but in no case should he make a change in the cable pair without the authority of the record clerk who has charge of this work at the office of the company. If a change is made in the conductor assignment, the installer should note on the face of the order the new conductors employed.

MISCELLANEOUS POINTS

53. The installer should note particularly whether the apparatus he is installing is defective in any way, for he is held responsible for the adjustment of bells and contacts and for the condition of all connections. Apparatus with minor defects that will not interfere with the operation temporarily may be installed if it seems necessary, but the repair department should then be notified at once concerning the nature and extent of the defects. Temporary installations should generally be avoided, and when they do seem necessary, the facts should be noted on the order, together with all the reasons for the action taken.

54. All apparatus should be handled carefully. Instruments should not be lifted or be carried by cords, switches, or the binding posts. All apparatus and material liable to damage by moisture or dampness should be properly protected while in transit between the office and the subscriber's premises. All apparatus returned from the subscriber's premises should be plainly marked with a tag, showing the name and address of the subscriber, the nature of the defect, the reason for the change, the installer's name, and any other information that may be of service to the company.

55. The standard plans for interior wiring prescribed by the company should be followed closely in all cases. If a subscriber insists on an arrangement of the interior wiring according to his own ideas, an attempt should be made to conform to his wishes, if this can be done without changing the standard plans of wiring. If not, the foreman or the proper authorities at the office should be consulted, and a special effort should be made to see that the subscriber is thoroughly satisfied with the installation before leaving the job. Any deviation from the original plans should be noted on the order, together with the reasons therefor.

56. When a telephone is to be moved from one part of the subscriber's premises to another, all of the wiring to the new location should be completed before disconnecting the instrument, so that the interruption of service will be brief.

All wiring and cable removed from the premises of a former subscriber should be coiled and tagged .The tag should bear the installer's name, date of removal, and the size, type, and condition of the equipment removed. Instruments or substation equipment removals should be handled in the same way.

The equipment removed from a subscriber's premises should be turned in to the storeroom as soon as possible after the removal. The cost of removing interior wiring from the premises of a former subscriber will usually offset the return obtainable from the wire itself, especially in private residences. If such wiring is in good condition, it should usually be left for possible future use.

MAINTENANCE OF SUBSCRIBERS' EQUIPMENT

GENERAL INSPECTION AND TESTS

57. The equipment for subscribers' telephones is widely scattered, and its close supervision is impracticable. If trouble does occur, some delay in making the necessary repairs is unavoidable, and dissatisfaction with the service may result. For these reasons, especial care is taken to prevent the occurrence of trouble. In large plants, the equipment of subscribers is inspected periodically. Each inspector examines regularly the telephone equipment in a given territory and clears the instrument troubles arising in his district.

In large exchanges, the inspectors report to the wire chief, who is held responsible for the maintenance of telephone lines and apparatus. In the morning an inspector receives a number of routine cards directing him to inspect certain stations, which he does, reporting by telephone as each station is inspected. This regular inspection work continues throughout the day unless trouble is reported, but the regular work is abandoned at any time in order to find and clear trouble. While in the homes and offices of subscribers, the inspector should be governed by the same rules and suggestions concerning deportment and general demeanor as given for the installer.

58. An inspector's test set as generally used in testing for trouble in common-battery instruments is shown in Fig. 27;

it consists of a receiver and a transmitter mounted on a single handle. A receiver alone is sometimes used.

The testing equipment commonly used in local-battery systems consists of an inspector's set as just described, or in many cases merely a receiver, and also a magneto generator with polarized ringer or buzzer, an induction coil, and a pair of dry cells. All except the test set are packed in a small case equipped with a suitable handle for carrying. A battery gauge for measuring the voltage of dry cells is also a useful adjunct to the inspector's equipment in local-battery exchanges. The gauge generally used is in reality a small galvanometer about the size of a watch. Its resistance is such that when connected across a single cell the current in the cell and the gauge will be about the same as through an ordinary carbon transmitter. The cell voltage is therefore measured at normal current.

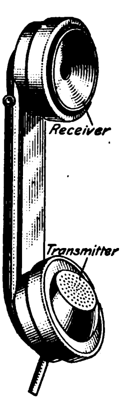


FIG. 27

59. The inspector's tool kit should contain tools and duplicate parts of apparatus so that he can make permanent repairs in ordinary emergencies without the necessity of extra trips to the office. Each telephone company usually prescribes a list of tools, consisting of pliers, wrenches, screwdrivers, wire cutters, etc., for its inspectors to carry. This list also includes the necessary supplies, such as tape, solder, and metal polish. An equipment of standard parts for the telephone sets in use is also specified, including receiver cords, transmitter mouthpieces, and receiver ear pieces.

60. Routine Inspections.—A subscriber's station instruments and connections should be inspected with the following specific points in view: Examine the inside wiring, auxiliary apparatus and equipment, window-connecting block, protector, and leading-in wires. Examine and test the ground connection. Clean the apparatus, both outside and inside. Examine the screws, lugs, binding posts, and all soldered connections, both outside and inside. Examine the receiver, removing the cap and the diaphragm. Test the strength of the permanent magnets; make sure that the diaphragm does not touch the poles and that no dust or foreign matter is in the receiver cup. In replacing the diaphragm, put the black enamel side away from the poles. Test the receiver cord. Test the receiver and the transmitter by talking with the central office. On magneto installations, test the battery, and, if necessary, substitute a new one. Examine the adjustments of the relay and the bell. Test by having the operator ring on the circuit. If not working properly, make the necessary adjustments.

In making the first inspection after the installation of a desk stand, the inspector should open and examine all the connections inside of the stand to make sure that the installer made no mistake in connecting the cord conductors. The cord in a common-battery desk stand can be so connected that the instrument will work, but at less than its full efficiency.

61. A private branch exchange of either the cordless or the cord type should be inspected as follows: Clean the nickel-plated parts, drop shutters, cord plugs, and glass over all signals and woodwork. Remove the dust from the back of the switchboard. Examine and dust out the wiring terminal box. Examine and test the battery and ground connections, fuses, and protectors. Test the polarity of the battery supply leads and make sure that the current strength over such leads is sufficient to operate properly all relays and signals when all cords are up. Test the polarity of all trunks, making sure that the ground is on the proper side. Test the generator feeders, making sure that the leads are not reversed. Examine and test the cords, operator's set, listening and ringing and other keys, buzzer circuits, holding coils, relays and cord signals, cord relays, buzzer relays, and retardation coils. Inspect the cord weights, ascertaining that their pulleys work freely and that the cords are not tangled. Make sure that all jacks, drops, and signals perform their functions properly. Examine all the resistances, testing them for short circuits and opens. Examine all the cable within the cabinet and leading to the cabinet.

62. Terms Used in Telephony.—In the work of testing for and clearing trouble in the various branches of telephone work, use is made of certain expressions that should be familiar to those dealing with central-office equipment and apparatus. Knowledge of these expressions at this time is necessary, since they must have certain dealings with the central office in carrying out the work of testing the station equipment of subscribers.

The expressions *tip side of line*, *ring side of line*, *live side*, and *dead side*, as well as *opens* and *shorts*, have already been explained. A **cross** is a contact between conductors of two different circuits. An **open**, or *break*, in a circuit may be *dead open* or *partly open*, according to the completeness of the break, or its resistance. Grounds may be referred to as *dead* or *high resistance*, according to their nature. Opens, crosses, and grounds may also be of an intermittent nature, owing to swinging conductors.

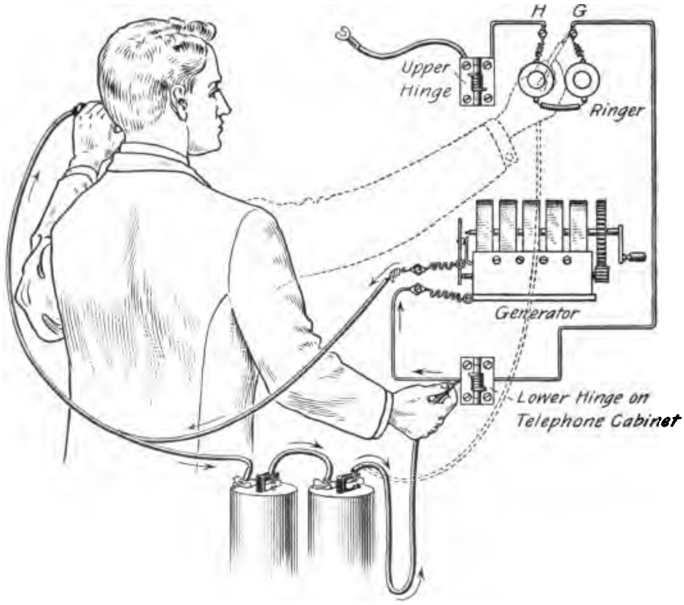


FIG. 28

Apparatus is said to be correctly **poled** when so connected in a circuit that the direction of the current through it is correct; the process of making such connections or testing them for accuracy is called *poling* them. For example, the direction of current through a telephone receiver should be such as to increase rather than to decrease the strength of the permanent magnets, and when so connected, the receiver is correctly poled.

63. Tests With a Telephone Receiver.—The telephone receiver is the most useful of all the testing instruments employed in telephony; a wide variety of tests can be made with it. The operator's head receiver is the most convenient form for testing purposes, since it permits the tester to use both his hands. To one experienced in the use of a receiver, the loudness of the click or noise produced in it when its terminals are connected across a circuit in which there is a source of current, the ease or difficulty with which a tester is able to hear a distant speaker, and the *side tone*, or the sound which his transmitter causes in his own receiver, will often enable the tester to judge whether the trouble is far away or near by, and something of its nature.

64. Fig. 28 illustrates a test for the continuity of the circuit through the generator in an ordinary series magneto telephone. The receiver is connected in the circuit between the generator and one battery terminal, and a wire connected with the other battery terminal is used to make contact with different points along the circuit being tested. This wire therefore forms an exploring terminal. If the circuit is continuous up to the lower hinge of the telephone door, a click will be heard when that point is touched. If, when the bell terminal is touched, as indicated by dotted lines, no click is heard, it will be known that the circuit is open somewhere in the wire leading from the hinge to the bell. Then by tracing back on the wire the exact location of the break may be found. By methods such as this the exact location of any break in a circuit that is within reach may be determined.

In a similar manner, shorts, crosses, and grounds may be detected and located. When the two terminals of the test circuit are applied to objects that are insulated from each other, no click will result, but a click will occur if a conductive path exists between them. Care must be taken, however, not to be misled by clicks that are caused by charging current when highly insulated conductors lie close together thereby giving them capacity, or causing them to act as a condenser.

65. A method of testing receiver cords or switchboard cords is illustrated in Fig. 29. With one end of the cord connected to a battery and the other end to a receiver, continuous-current electricity will flow through the receiver. The cord is then shaken, as indicated by the dotted lines, while the receiver is held to the ear. If the conductors and the insulation are in good condition, no sound will be heard in the receiver; but if the conductors are broken or if the insulation is poor, a grating and rattling noise will be heard. In common-battery systems such tests can usually be made with current from the central-office battery.

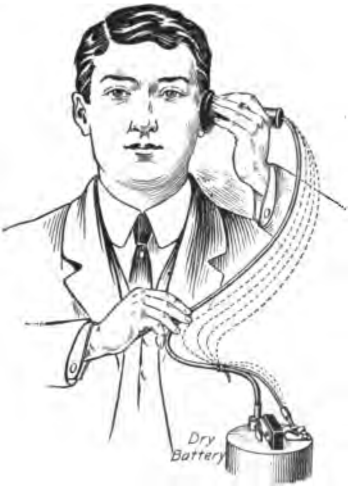


FIG. 29

66. A convenient way to test a transmitter on either a local- or common-battery set is to hold the receiver to the ear and gently tap the transmitter. The sound in the receiver will show not only whether the circuits are live or dead but will also give some indication as to whether the transmitter and receiver are in proper working order. After sufficient experience has been gained, one may judge rather accurately as to the working condition of the transmitter and receiver by talking into the transmitter and listening to the *side tone*, a name given the sounds heard in the receiver.

SUBSCRIBER'S STATION TROUBLES

67. Among the causes of trouble at a subscriber's station are opens, shorts, and grounds. Any of these troubles may arise in the wiring leading to the instrument or in the instrument itself. Tests at a local-battery station are made by the use of a magneto or the inspector's test set in connection with his test battery. The necessary tests will be suggested by the following description of tests at a common-battery station.

68. Common-Battery Wiring Tests.—If an instrument is found dead, that is, with no voltage, or battery, at the line binding posts, a test should be made first at the protector, or window-connecting block, by simply connecting the test receiver across the line there. If a click is heard in the test receiver when this connection is made, the inside wire must be open. If no click is heard, open the line at the protector and again test the line. If no click is heard now, the trouble is outside, but if battery is found across the outside wires, the inside wire must be short-circuited or grounded.

To test the inside wire, leave it disconnected at the window block, place one terminal of the test receiver on one inside wire and tap the other terminal to first one and then the other binding post of the line. Repeat this test on the other inside wire; in either case, a click in the test receiver indicates that the inside wire or instrument is grounded. If no click is heard in either test, connect one inside wire to the line at the protector, and test between the other post and the other inside wire. A click in the test receiver indicates a short circuit on the inside wire or in the instrument. Now reconnect the wires at the protector, disconnect the line wires at the instrument, and repeat there the tests for short circuits, opens, and grounds in the instrument, leaving the receiver on the hook. If the trouble is not found in the instrument, it must be in the wiring between the instrument and the protector.

69. Common-Battery Instrument Tests.—To locate an open in a common-battery instrument, leave the receiver on the hook and all connections in place. Hold one terminal of the test receiver on one line binding post, which for convenience may be designated as No. 1, and explore with the other terminal from the other post, No. 2, along each circuit to the hook switch, touching each available point in the circuit. At each touch the receiver will click until the open is passed, when no click will be heard. Repeat the test by holding one test terminal on binding post No. 2 and with the other terminal explore each circuit between binding post No. 1 and the hook switch.

70. Such tests do not fully reveal the condition of a condenser in a circuit, for when the exploring terminal touches the circuit at a point beyond the condenser a click will be heard unless a conductor is actually broken in the condenser. If the condenser is in normal condition, the charging current causes a click. To ascertain whether a normal condition instead of a short circuit causes this click, the two terminals of the test receiver can be touched to the condenser terminals when the condenser is normally connected across the circuit; if no click is then heard, the condenser must be short-circuited, because if it were normal, the discharge current would cause a click. If a condenser in a common-battery circuit is open, that is, a conductor actually broken, no side tone will be heard when talking in the transmitter, except when a conducting strip is placed across the condenser terminals.

A short-circuited condenser will operate the relays of a party-line selective system; it will pull the bell strongly to one side on direct-line ringers and will operate the switchboard signals when the receiver is on its hook.

71. Miscellaneous Tests and Adjustments.—To test the cords and connections of a common-battery instrument, short-circuit the condenser with test clips, and shake the cord. No scratch or noise should be heard in the receiver.

72. To test transmitters of either local- or common-battery instruments, listen to the side tone while turning the transmitter slowly on its pivot through the full arc of its movement. The tone should be even and of good volume and should remain the same in every position of the transmitter.

73. The cap and diaphragm should be removed from the receiver, the pole pieces thoroughly cleaned with chamois, and all loose particles removed from the shell of the receiver. A straightedge, for example a pencil, resting on the edges of the receiver case, should not touch the pole pieces. If the diaphragm is dented, concave, or rusty, a new one should be substituted. When the diaphragm is in position it should be near the pole pieces but not touching them and should be held with a magnetic pull that is best determined by comparison with receivers known to be in good condition. The clearance of the diaphragm from the magnets can be determined by gently tapping it with a finger. Care should be taken not to rub the lacquer from the diaphragm.

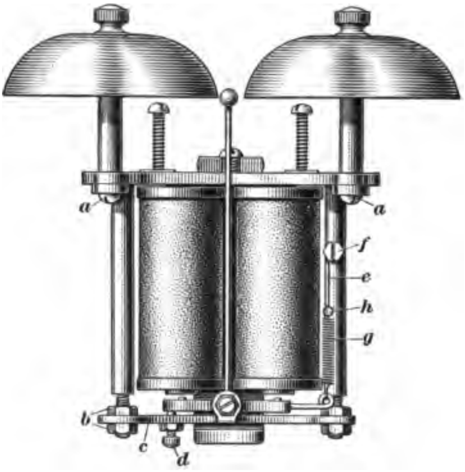


FIG. 30

74. The listening and ringing keys should be so adjusted that the outer contacts are normally open and the swinging, or movable, contacts engage the inner contacts without resting on the wedge. When the key is depressed, the inner contacts should break before the outer contacts make. The swinging contacts should engage the outer contacts before the key is fully depressed.

75. For the adjustment of bells the New York Telephone Company issues instructions substantially as follows: Loosen the screws *a*, Fig. 30, and separate the gongs as far as possible. By means of the adjusting screws *b* set the armature *c* so that the hammer can move through a space not greater than $\frac{1}{8}$ inch. Set the pivot screws as tight as may be without interfering with the free movement of the armature. Set each gong so that the hammer will strike the gong and rebound just enough to clear it when the armature is operated manually.

For four-party lines, in addition to the foregoing, raise the adjusting nut *d* until the end of the armature supported by it is a little nearer the pole piece than the other end is to the other pole piece. If the end of the armature to which the spring is attached touches the frame, move that end of the frame a little farther from the pole piece. The movement of the armature will then be controlled entirely by the screw *d* and the pole piece above it. The hammer should then move through a space not greater than $\frac{3}{32}$ inch when the armature is operated manually, and the gongs should be set as before described. The stem carrying the hammer can be bent slightly if necessary in order to get proper clearances.

Ring the bells electrically and increase the tension of the biasing spring until it stops the ringing. The upper end of the spring should then be at some point *e*. If the spring is so weak that the end must be drawn around the adjusting stud *f*, a stronger spring should be substituted. Now decrease the tension until the ringing again stops and the upper end of the spring is at some point *g*. Adjust the tension until the end of the spring is at a point *h* slightly below the middle point between *e* and *g*. The bells should be rung electrically only while adjusting the spring tension. When properly adjusted, the bells will stop and start ringing instantly when the relay contact is quickly opened and closed during a continuous ring.

76. Relays for selective instruments should be adjusted so that the armature moves freely on the trunnion screws without unnecessary play. The contact screw should make contact with the spring at a point half way between the extreme limits of the movement of the armature. The contact spring should have enough pressure to push the armature away from the pole pieces when the ringing current ceases. The relay is always to be placed in a vertical position.

77. The gravity switch should be adjusted to work freely and not bind at any point when the heel screw is set tight. The contact springs should make contact with the switch as nearly as possible at a point half way between the extreme limits of the movement of the switch. After reaching its highest point, no noise or cut-out should be heard on moving the switch slightly.

78. The desk-set cords should be checked for reversal by short-circuiting the receiver while listening. No click should be heard on magneto or four-party selective common-battery instruments, and only a slight click should be heard on direct-line common-battery instruments.

79. Final Test.—After all adjustments have been made and all connections inspected, a talking and ringing test should be made with all the apparatus in normal position.

CENTRAL-OFFICE EQUIPMENT

GENERAL FEATURES OF A TELEPHONE CENTRAL OFFICE

CLASSIFICATION AND DEFINITIONS

1. A **telephone central office** is commonly understood to mean a building or the part of a building in which the circuits from individual telephone subscribers are assembled at a switchboard for interconnection. In addition to the switchboard, the office equipment includes all the means for supporting and distributing the many circuits, the protector equipment, the means for generating the electric energy necessary to operate part or all of the system, and the desk equipments.

2. A **telephone exchange** is a complete system necessary to give telephone service to a district or a community. An exchange includes at least one central office and its equipment, and some large exchanges include several offices each of which is the center of an office district. A central office is often referred to wrongly as a telephone exchange; the latter term is much the broader, as it includes not only one or more offices but also all the interconnecting systems of conductors.

3. **Telephone switchboards** are classed as *single-position boards* and *multi-position boards*, a position being the part of the board before which a single operator works. Multi-position boards are designated by the number of positions, as *two-position boards*, *twenty-position boards*, etc. Boards having more than three positions are made and shipped in sections, which are assembled at the office side by side so as to form a continuous board. Three-position sections are most common, but

COPYRIGHTED BY INTERNATIONAL TEXTBOOK COMPANY. ALL RIGHTS RESERVED

two-position sections and even single-position sections are in use, the latter in very small exchanges.

4. Telephone exchanges are classed as *local-battery*, or *magneto, exchanges* and as *common-battery*, or *central-energy, exchanges*, according to the source of the energy for signaling and talking purposes. Local-battery exchanges were first in operation but are now little used except in small communities; common-battery exchanges are superior in many respects and have superseded the older method for all large exchanges.

5. Switchboards in which each subscriber's line terminates in only one jack are called *non-multiple boards* to distinguish them from *multiple boards*, in which each line has several jacks. In a non-multiple board, each operator must be able to reach all the jacks in order to complete connections with every subscriber's line. Such boards are usually limited to not over three positions so that an operator in the central position can reach all the jacks.

6. Each line terminating in a multiple board has a jack symmetrically located in each area over which the operator at the center of the area can reach easily. These areas usually coincide with the sections. The jacks are said to be *multipled* through the sections and are called **multiple jacks.** If a board is made up of three-position sections, for example, each line has a jack at every third position, that is, one jack in each section. Thus, the jacks at each position are exactly duplicated at the third position from it either way. Each operator can reach all the jacks at her position and at the adjacent position on each side. She can therefore make connection with every line terminating in the switchboard. The end positions can remain unoccupied.

7. Each subscriber's line is usually provided with only one signal, and adjacent to that signal is an answering jack. Each position at the board has as many of these signals and answering jacks as can be attended to readily by one operator. By means of the multiple jacks she can make all desired *local connections* with other subscribers' lines terminating in the same switchboard, and by means of *trunks* can obtain *trunked connections* with lines terminating in other switchboards.

8. **General Plan of Trunking.**—In very large exchanges the several offices are interconnected by trunks. One end of each trunk terminates in multiple jacks at the *subscribers' boards* just described, and the other end in a cord and plug at an *incoming trunk position* on a *trunk board,* which may be in a distant office. The subscribers' board is commonly known as an *A board* and the trunk board as a *B board.* An operator at an A board, who answers incoming subscribers' calls, is commonly known as an *A operator*, and the operator at a B board who answers only incoming trunk calls, is known as a *B operator.*

Subscribers' lines terminating in an office are multipled through both an A board and a B board. When an A operator receives a call for a connection with a subscriber's line terminating in another office, she plugs into an *outgoing trunk jack.* One of the B operators in the distant office receives the call and completes the connection. The work of each class of operators is special, and the trunks carry traffic, or calls, in only one direction

9. **Auxiliary Central-Office Equipment.**—The **main distributing frame** is the proper dividing line between the outside wires and cables and the central-office wiring. It is the point at which the various lines entering the office first appear. This frame has several functions, the principal one of which, and the one from which it derives its name, is to permit changes in the distribution between the various outside lines and the switchboard. If a subscriber moves and desires to keep the same telephone number, his old switchboard line can be connected at the main frame with another outside line leading to his new location. The main frame, therefore, provides for all necessary changes between the inside, or switchboard, lines and the outside lines.

10. Since the conductors of the outside cables terminate at the main frame, this is the logical place for the central-office protective apparatus, and therefore all subscribers' lines, except those that are wholly underground, are provided on the main frame with *heat coils* and *air-gap arresters.* As the main

frame is the dividing point between the inside and outside plants, and as the protectors themselves afford an excellent means of breaking the connection between the inside and the outside lines, this frame is also the logical point from which to conduct electrical tests.

11. An **intermediate distributing frame** is used in a large multiple-board office chiefly to adjust the work of the operators and to classify the calls. If some operators are found to have more calls than can be attended to promptly and others have some spare time, the connections of the line signals and answering jacks can be changed at this frame. The work can also be arranged here so that certain classes of service are handled at consecutive positions on the switchboard.

12. The **power plant** is a vital adjunct to the telephone office, particularly in the case of common-battery exchanges. The power plant consists of the storage battery, from which all talking current and, in fact, all direct signaling current is drawn; also, the necessary machines or devices to charge this battery, together with the other machines for generating ringing current or other kinds of signaling current. The power plant must be safeguarded against breakdown in all possible ways; if it should become completely disabled, the entire service of the office would be suspended.

13. The **desk equipments** required to operate a telephone exchange are in reality small switchboards, usually of the desk type, equipped with various apparatus for facilitating the work of the chief operator, monitors, information clerks, wire chief, and other minor officials.

MAGNETO SWITCHBOARDS

GENERAL DESCRIPTION

14. The general operation of non-multiple magneto, or local-battery, switchboards in central offices is practically the same as in private-branch exchanges previously described. Familiarity with the preceding description of such boards will be an aid in understanding what follows. Multiple magneto switchboards have practically gone out of use.

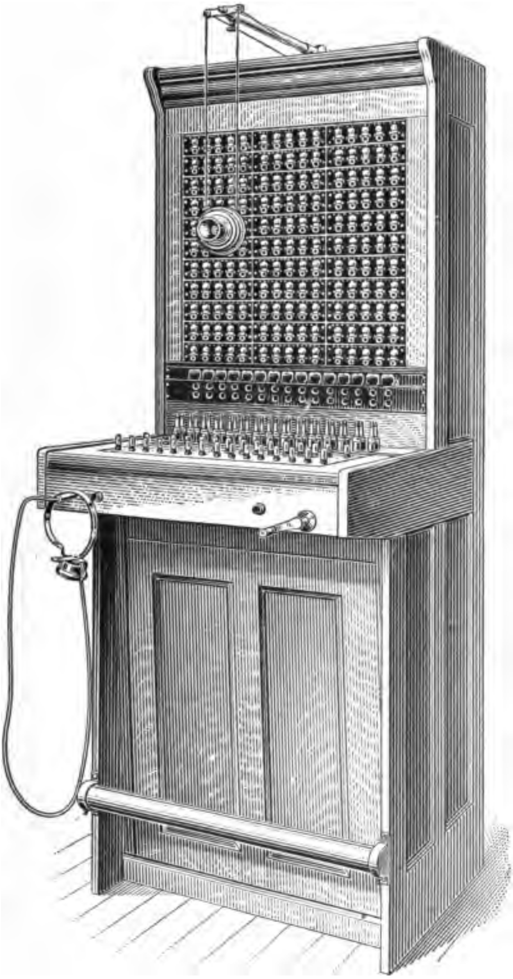


FIG. 1

15. Fig. 1 shows the front of a single-position, central-office magneto switchboard equipped with signal lamps. Fig. 2 shows the rear of a switchboard of the same general type but equipped with drops in place of signal lamps. The rear panel, which normally encloses the wiring and apparatus, is removed to show the interior. The signal lamps and jacks on the face of the board, Fig. 1, are mounted in strips of five, each jack being directly under its corresponding lamp. The board has three panels, each with eleven strips of five lamps and jacks, making in all a capacity of 165 lines. This is an unusually large number for a single-position magneto board and indicates that this particular board is intended to serve a group of lines on which the number of calls per day on each line is comparatively small, otherwise one operator could not attend to so many lines. Immediately below the bottom row of jacks is a row of clearing-out drops, there being fifteen of these in all, one for each pair of plugs and cords. The plugs are mounted on the stationary part of the shelf back of the hinges of the keyboard. The plug shelf and the face of the board just back of the plugs are usually covered with heavy sole leather to resist the wear caused by impact of the plugs when they return to their seats. Fifteen pair of plug and cords, with corresponding ringing and listening

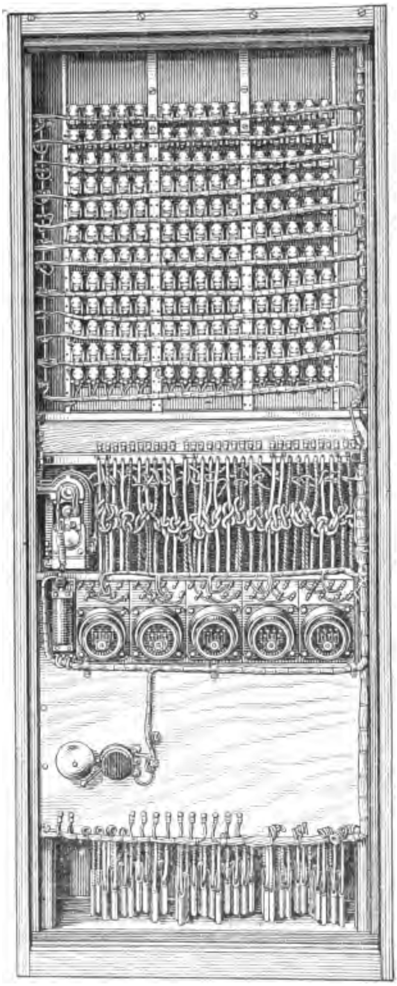


FIG. 2

keys, are shown, thus permitting fifteen simultaneous connections between lines on the board. This number of cords and plugs may be considered a maximum for magneto boards, an operator being unable to handle a greater number under ordinary circumstances. The function of the generator switching key, shown near the generator handle, is to switch from hand to power ringing.

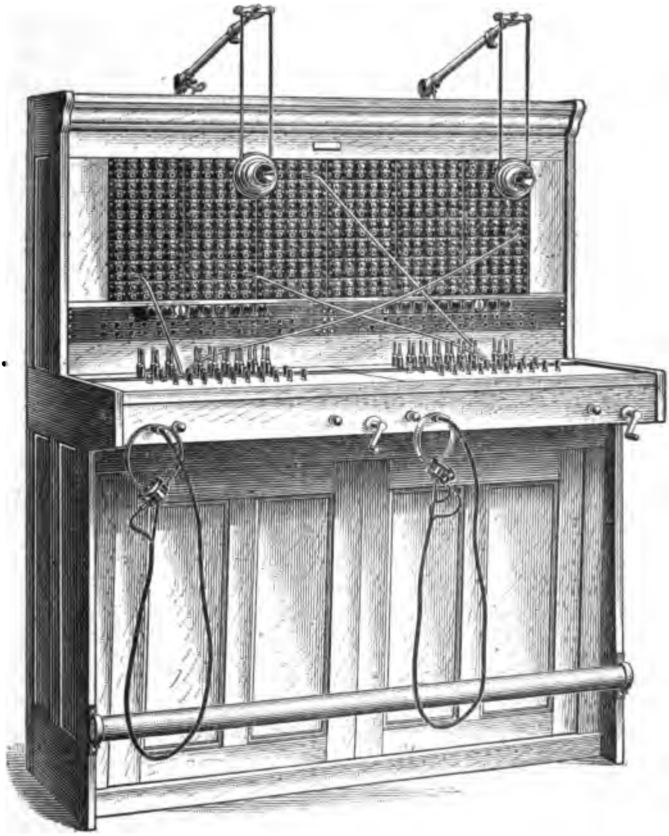


FIG. 3

An extra set of springs is used in connection with each key lever in front of the left-hand five pair of cords and plugs. These springs constitute the repeating-coil keys and are for the purpose of switching repeating coils into or out of the cord circuits, as will be described later. The corresponding repeating coils are shown at the back of the board, Fig. 2.

The cords of each pair in this particular board are colored, beginning at the left, Fig. 2, red, white, green, red, white, green, etc. This feature is special, but is sometimes employed to help avoid mistakes when taking down connections. The screw terminals shown near the bottom, Fig. 2, are for the power wiring circuits, such as power ringing, transmitter battery, night-alarm battery, etc.

16. In Fig. 3 is shown a front view of a two-position magneto board of a type that is, in general, similar to that shown in Fig. 1. Each of these positions is equipped for only 105 lines, a more usual number.

OPERATION OF CIRCUITS

17. Fig. 4 shows the normal condition of a magneto line equipped with a drop signal before the subscriber signals the operator. Fig. 5 shows the condition of the same line while the subscriber is turning his generator crank. This causes the shutter to fall and thus conveys a signal to the operator.

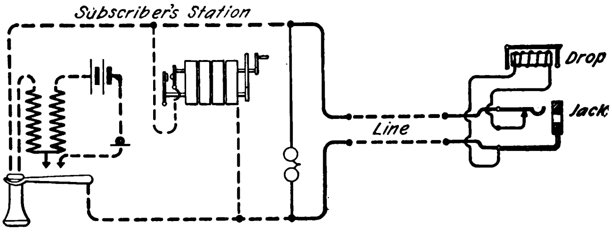


FIG. 4

The next step is the answering of the call by the operator, which is shown in Fig. 6. The subscriber has released his generator handle and removed his receiver from its hook, thus eliminating the generator from the circuit and closing the talking circuit. The operator has responded to the call by inserting the answering plug *a* into the subscriber's jack, automatically disconnecting the drop from the circuit by lifting the tip spring from its normal contact. The operator has also connected her telephone set into the circuit by means of the listening key *L K*.

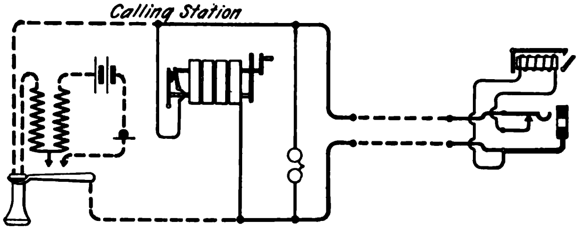


Fig. 5

18. The cord circuit consists of a single pair of conductors, extending from the tip and sleeve, respectively, of the answering plug *a* to the tip and sleeve of the calling plug *b*. Permanently bridged across this cord circuit is the coil of the clearing-out drop *C O*. The listening key serves merely to bridge the secondary circuit of the operator's telephone set across the cord pair. The primary circuit of this set includes the operator's transmitter, the battery, and the primary winding of the induction coil.

19. Having learned from the subscriber the number of the line desired, the operator next inserts the calling plug *b* into the jack of that line and throws her ringing key, as shown in Fig. 7. The calling line is thus connected with the called line through the cord circuit, and the drop of the called line is disconnected from the circuit. The ringing key *R K* connects

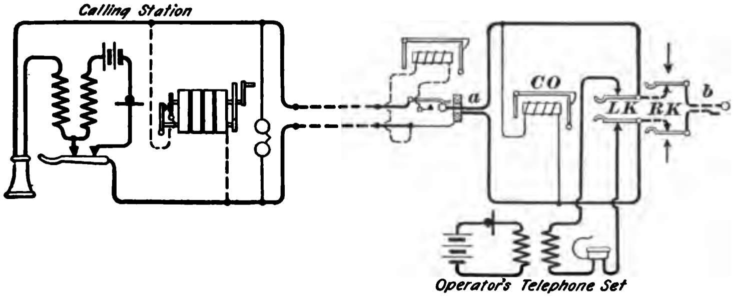


Fig. 6

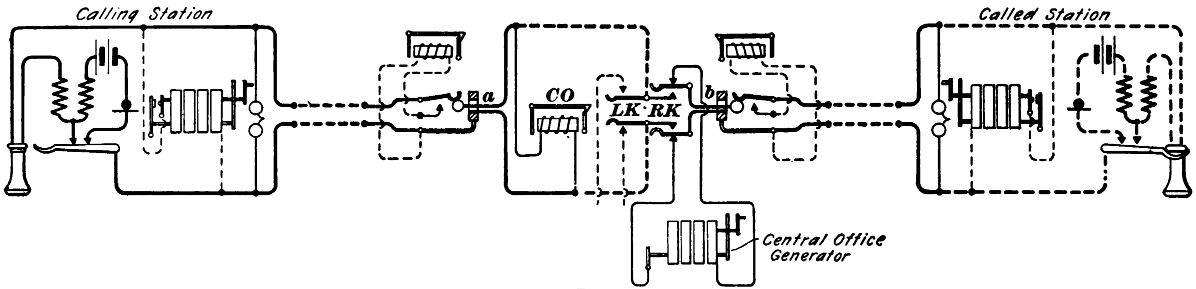


FIG. 7

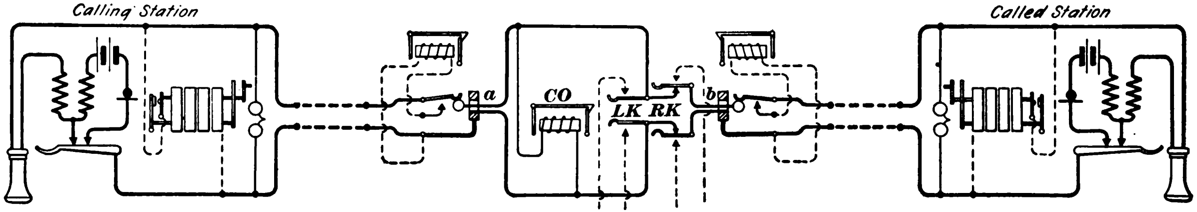


FIG. 8

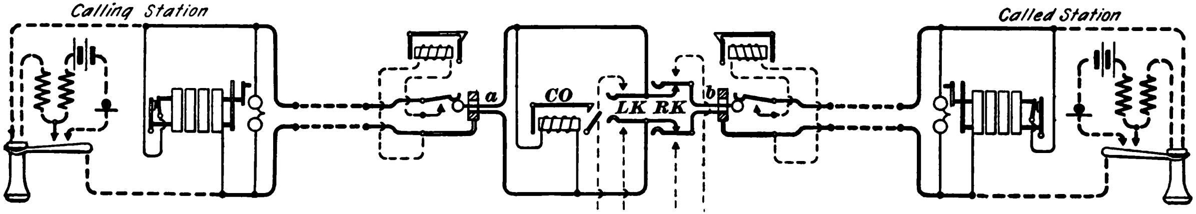


FIG. 9

the central-office generator with the called line and at the same time disconnects the answering side of the cord circuit. This break in the cord circuit is to prevent ringing current from going back to the calling station and ringing in the ear of the waiting subscriber at that station. As the ringing key in such boards is usually operated by the same lever as the listening key, the throwing of the lever into its ringing position removes the operator's talking set from the circuit.

20. In Fig. 8 is shown the completed connection between two subscribers, the called subscriber having responded and removed his receiver from its hook and the operator's ringing key having been thrown back into its normal position so as to leave the two ends of the cord connected. All obstructions have been removed from the circuits connecting the two instruments, and the talking circuit is continuous from the tip side of the calling line, through the tip strand of the cord, to the tip side of the called line, thence through the talking apparatus at that station, back over the ring side of the called line, through the ring strand of the cord, to the ring side of the calling line, and through the talking apparatus of that station.

When the conversation is ended, the subscribers hang up their receivers, and they are supposed to turn their generator handles, to *ring off*, that is, to give the clearing-out signal to the operator. This condition is shown in Fig. 9, the clearing-out drop *C O*, the only drop remaining connected with the circuit, having been thrown by this operation. The operator then removes both plugs, restoring both lines to their normal conditions.

One of the weaknesses of the magneto switchboard is that subscribers frequently do not remember to send the clearing-out signal. This signal cannot therefore be relied on, and operators are compelled to listen in occasionally in order to determine when connections can be taken down.

REPEATING COILS

21. In a magneto board, the two parts of a cord circuit are frequently separated by a **repeating coil,** which is merely an induction coil, usually with a 1-to-1 ratio. The function of this coil is to connect the two parts of the cord by induction rather than conduction. The principle of the repeating coil is shown in Fig. 10, and its application to a cord circuit in Fig. 11. Voice currents in the circuit of either winding of the coil will cause the induction of electromotive force in the other winding. Fig. 11 shows a cord circuit suitable to connect a metallic-circuit line with a grounded line. Voice currents in either line will then be repeated in the other, while actual metallic connection between the two lines is avoided. A grounded telephone line is likely to be noisy, due to inductive effects, and if connected metallically with a metallic-circuit line, both lines may be noisier than either would be alone. A repeating coil in the connecting cord circuit tends to avoid noise troubles in the metallic circuit.

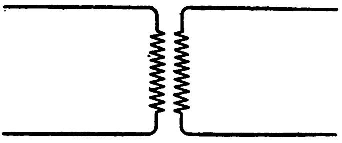


FIG. 10

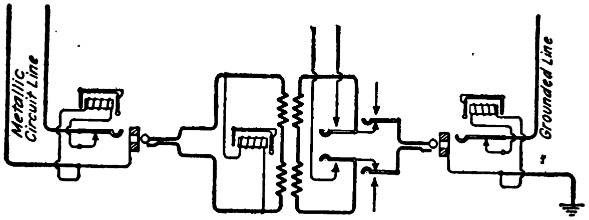


FIG. 11

22. The common practice is to insert repeating coils in some of the cord circuits of magneto switchboards and to use these cord circuits when lines of dissimilar type are to be connected. Such cords are useful for connecting not only grounded and metallic lines, but with modifications may also be used to

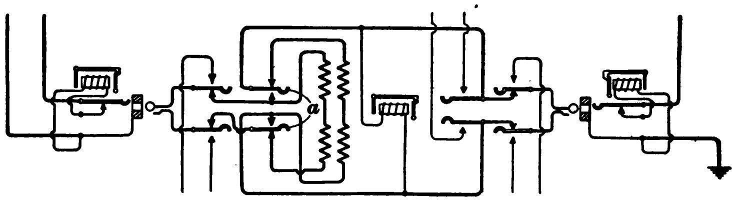
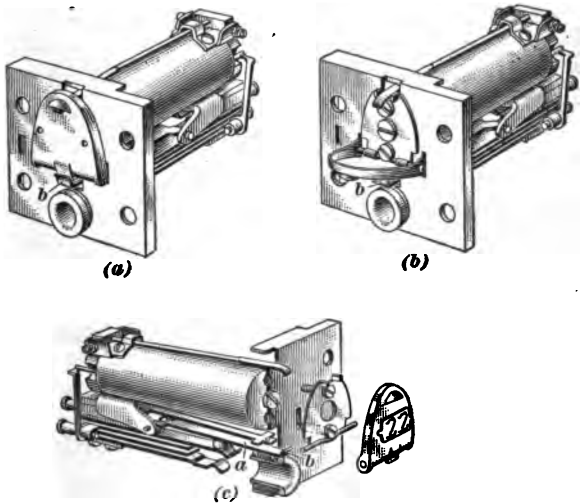


FIG. 12

connect magneto lines and common-battery lines. Even when the lines are all metallic circuits and supposed to be alike, the condition of some may become poor, owing to accidental grounds, and a repeating-coil cord circuit is useful in connecting a poor line with a good one. *Repeating-coil keys* are frequently provided for switching these coils into and out of circuit, thus making the circuit *convertible*. Fig. 12 shows a convertible cord circuit with the repeating coil in circuit; by means of the repeating coil key *a*, the coil can be cut out of circuit.

DROPS AND JACKS

23. The drops on a magneto board may be separate from the jacks or combined with them; these drops may also be of the hand-restoring or the self-restoring type. Fig. 13 shows a combination type; in view (*a*) the shutter is raised, in (*b*) it is down, and (*c*) shows the construction, but with some of the parts slightly separated and shown out of their true positions. When a plug is inserted in a jack, the lever *a* is raised, forcing the upturned lip *b* against a lug on the shutter, which is thereby restored automatically.



(a) (b) (c)

FIG. 13

24. Drops may be associated with jacks in a variety of ways, so far as their circuit arrangement is concerned. In Fig. 14 is shown, in symbolic form, several arrangements of drop and jack. The arrangements shown in (*a*) and (*b*) are the ones usually employed; (*a*) shows a single cut-off jack and (*b*) a double cut-off jack. In the arrangement shown in (*c*) an extra contact is provided near the armature of the drop. By this means the armature closes a local circuit during the ringing interval, and thus provides means, if desired, for giving an audible code signal.

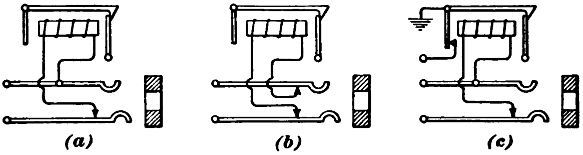

(*a*) (*b*) (*c*)

FIG. 14

25. Practically all of the magneto drops have their shutters so arranged as to close a local circuit when the shutter falls, this being termed the *night-bell*, or *night-alarm*, attachment. The regular night alarm gives a continuous audible signal from the time the shutter falls until it is restored. It does not, therefore, lend itself to code ringing. In this respect the arrangement diagrammatically shown in Fig. 14 (*c*) is superior, since the local contact is closed only while the ringing current is on the line. A vibrating bell or buzzer will, with this arrangement, respond to code ringing, and thus, in the case of party lines, permit the operator to judge whether the call is for her or for some other station on the line.

COMMON-BATTERY SWITCHBOARDS

ADVANTAGES

26. The principal advantages of the common-battery over the magneto system are those due to the centralization of the source of energy and the simplification of the method of signaling the central office. The elimination of the local battery and the magneto generator from the subscriber's station equipment not only permits the use of more compact and, therefore, more sightly instruments, but effects an appreciable saving in maintenance by decreasing the number of parts to be kept in repair. The incandescent lamp is in every way a better signal than the magnetic drop, being more simple and compact, and affording a better display. The ability to use signal lamps is one of the chief advantages of the common-battery system. This system is in use in practically all the larger communities, the use of the magneto system being confined to small rural communities where sources of electrical power are either entirely lacking or are of an uncertain nature and where the subscribers' lines are generally long.

NON-MULTIPLE COMMON-BATTERY BOARDS

27. The method of operating line relays and lamp signals is shown in Figs. 15 and 16, the former showing a single relay and the latter several relays energized by current from one battery. Fig. 16 also shows the connections of a pilot lamp, which lights with any signal lamp in the group with which it is associated. The connections of each line relay in Fig. 16 are the same as those of the one relay of Fig. 15. In either case the circuit of a line relay is closed whenever a receiver on that line is removed from its hook, the circuit being from the battery through the relay–a line wire–the telephone at which the receiver is lifted–the other line wire–ground–to battery. The relay then closes the lamp circuit and the lamp glows. The current in any lamp, Fig. 16, must pass through the pilot relay, thus closing the circuit of the pilot lamp and causing it to glow also.

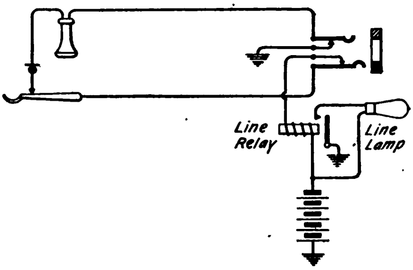


FIG. 15

28. Any number of line signals can be thus operated by current from one battery, provided the battery is large enough. Usually, one pilot lamp serves for all the lines terminating in one position. This lamp has a larger lens than the line lamp and is placed in a more conspicuous position; its function is to attract attention to the fact that a call exists at that position. When the answering plug is inserted in the jack, one line wire is disconnected from the relay and the other from ground, thus extinguishing the line signal lamp of that circuit and the pilot lamp if there is only one call on that position.

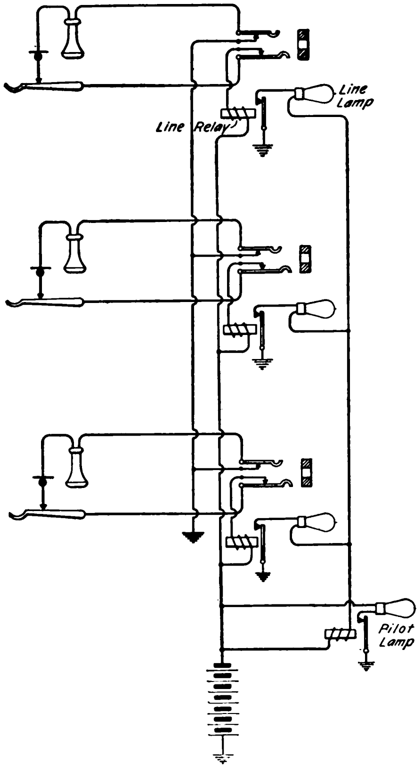


FIG. 16

29. In Fig. 17 is shown a diagram of a typical cord circuit connecting two simple line circuits. The four different battery representations are simply indications of the different connections of one battery. The positive pole is grounded and the negative pole is connected at each point where the battery is indicated. The current paths through the lines include the line relays and these relays close the circuits through the line lamps and the pilot relays. When a plug is inserted in a line jack, the path through the line relay is broken, and another path for line current is completed through the double-wound cord-circuit, or supervisory, relay and the tip and ring sides of the cord.

When the receiver on line *A* is removed from its hook, the line relay is pulled up, causing the lamp circuit to close and the line lamp to glow. The pilot relay is energized by this lamp current, thus closing the pilot-lamp circuit and lighting the pilot lamp. In response, the operator inserts the answering plug into

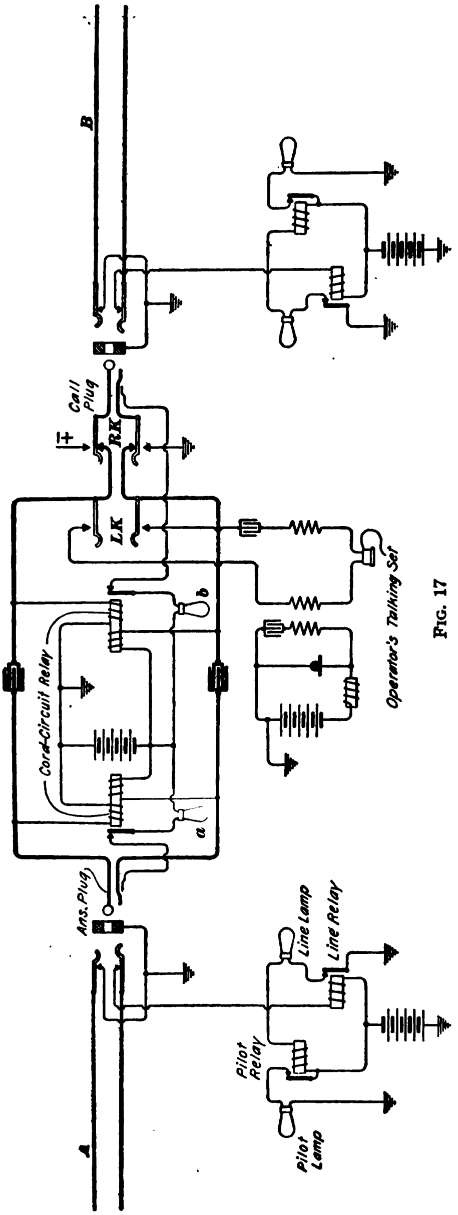


FIG. 17

the jack, thus cutting off the normal current supply to the line through the line relay and establishing another path for talking current through the two windings of the answering supervisory relay. The sleeve of the jack is permanently grounded, and the insertion of the plug therefore closes a contact in the circuit of the supervisory lamp *a*. This lamp is not lighted at this time, however, because the answering supervisory relay is energized, and the lamp circuit is held open thereby. When the receiver on the calling line is hung up, however, the circuit of the supervisory relay is opened, the armature of this relay falls back, closing the circuit through the supervisory lamp *a*, and the lamp lights.

30. When the answering plug is first inserted in the jack of the calling line the operator throws the listening key *LK* and learns from the calling subscriber the connection desired. She then inserts the calling plug in the jack of the called subscriber's line and throws the ringing key *RK*, thus causing the bell of that subscriber to ring. The path for current to this line is now through the supervisory relay associated with the calling plug. As the receiver of the called subscriber is on its hook at the time this connection is made, the calling supervisory relay is not energized; the supervisory lamp *b* therefore lights and continues to glow until the receiver on the called line is lifted from its hook. This act closes the line circuit through the supervisory relay, energizes this relay, and opens the circuit of the lamp *b*. The operator, seeing that both supervisory lamps are out, will know that the subscribers are engaged in conversation. When either receiver is hung up, the corresponding supervisory lamp will light, because the corresponding supervisory relay will be deenergized. When both signal lamps glow again the operator pulls down the connection.

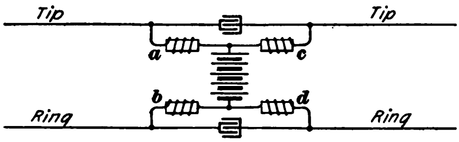


FIG. 18

31. Fig. 18 shows in simple form the circuit by means of which current is supplied to the subscriber's station during a connection. The supply to each cord and, therefore, to each line is through the relay windings, which also serve as impedance coils. The two condensers completely interrupt the conductivity of the tip and ring sides of the cord circuit. The pairs of coils *a b* and *c d* are of such high impedance that voice currents do not pass through them, but their resistance is not enough to prevent the steady current needed to energize the subscribers' transmitters. The condensers, on the other hand, permit the voice currents to pass freely between stations.

MULTIPLE COMMON-BATTERY BOARD

32. The principles governing the operation of the multiple common-battery switchboard are exactly the same as those of the non-multiple board. In the multiple board, however, each

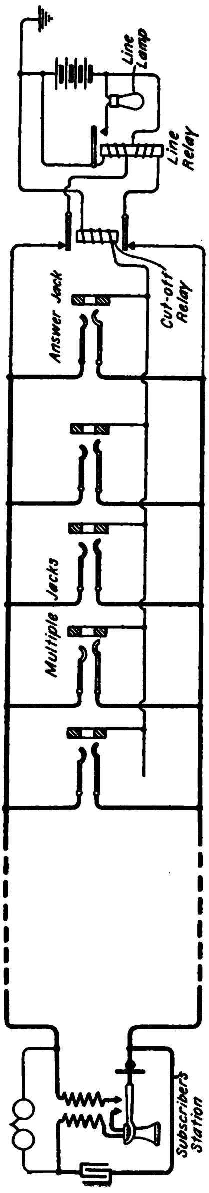


FIG. 19

line has a number of jacks, one on each section of the board, termed multiple jacks, and in addition to these one answering jack. As no one operator can see all of the jacks of a line, a busy test is provided for preventing two or more operators making connection with the same line at different jacks. This test is the chief distinction of the multiple board from the non-multiple board, which requires no such safeguard. The standard multiple board of the Bell companies is the No. 1 relay board.

33. Line Circuit.—The simplified line circuit of a No. 1 relay board is shown in Fig. 19, no attempt here being made to show the relative positions of parts. The tip and ring sides of the line pass from the subscriber's instrument to the tip and ring contacts of all the jacks, both multiple and answering. Only four multiple jacks are shown in this diagram, but there may be any number, or one for each section of the switchboard. Boards having as many as twenty-five multiple jacks for each line, one for each of twenty-five sections, are not uncommon. The tip and ring sides of the line beyond the connection with the last jack pass to the two back contacts on the cut-off relay. From this point the tip side of the line can be traced through a movable contact of the cut-off relay and one winding of the line relay to ground. The ring side of the line can be traced through the other movable contact of the cut-off relay and the other coil of the line relay to the battery. These two coils of the line relay are not differential, but, on the contrary, assist each other in magnetizing the core. When the cut-off relay is in its normal position, as shown, the line circuit, reduced to its simplest form, shows the two coils of the line relay and the battery in series in the metallic circuit of the line, this circuit being open only at the hook switch of the subscriber's station. Consequently, the line relay will be responsive to the movements of the subscriber's hook, the cut-off relay performing no part in the operation. The line lamp is controlled by the armature of the line relay, as indicated.

34. All the sleeve contacts of the jacks are connected together and grounded through the coil of the cut-off relay. These sleeve contacts cooperate in closing the circuit of the cut-off relay when a plug is inserted in a line jack and also serve as test contacts. If the tip of a calling plug is touched to a sleeve contact of a line that is in use a sound known as the *busy click* is caused in the operator's receiver.

In comparison with the non-multiple board with one jack per line, Figs. 15 and 16, the multiple board, Fig. 19, has several jacks of a much simpler type, having only three contacts with no makes and breaks. This greater simplicity of the jack is a vital feature in large multiple boards, partly on account of lower first cost and partly on account of less cost of maintenance. The simpler jack is permitted by the use of the cut-off relay in the multiple board, this relay, as will be shown, operating when inserted into a jack to cut off the line beyond the jacks just as the cut-off jack does in the non-multiple board. By having these switching functions performed by the cut-off relay instead of by the jack, a great saving is made, because one relay will serve for all of the jacks on a line. Furthermore, this relay can be mounted in another room from the switchboard, where its contacts may be much more readily inspected than could the contacts of the jacks in a large multiple board.

35. Cord Circuit.—The cord circuit of a No. 1 board is shown in Fig. 20. The battery supply to this cord circuit is by the repeating-coil method. When two lines are connected by this cord circuit, the path of the line current can be traced from the ground through the two windings of a repeating coil in parallel–tip sides of cord and line–transmitters in the two connected instruments–ring sides of line and cord–supervisory relays and their resistances–repeating coils–battery. The resistance shunting each supervisory relay forms a path that is readily traversed by voice currents. No current can be set up in either supervisory relay except when the plug with which it is associated is in a jack of a line with the receiver off the hook. This fact places the supervisory relay under the control of the subscriber on a line with which it is connected, just as is the line relay before the connection is made between the answering plug of the cord circuit and the jack of the subscriber's line.

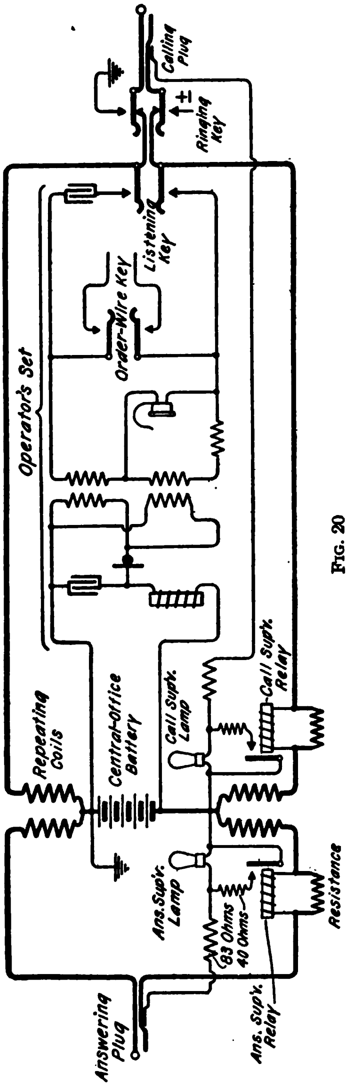


FIG. 20

Each supervisory lamp is in a circuit with a resistance of 83 ohms between the live side of the battery and the sleeve conductor of the cord. When the plug is in a jack, the lamp glows unless the line relay is excited, in which case the lamp is shunted by a resistance of 40 ohms and hence does not glow. The ringing and listening keys operate in the usual way.

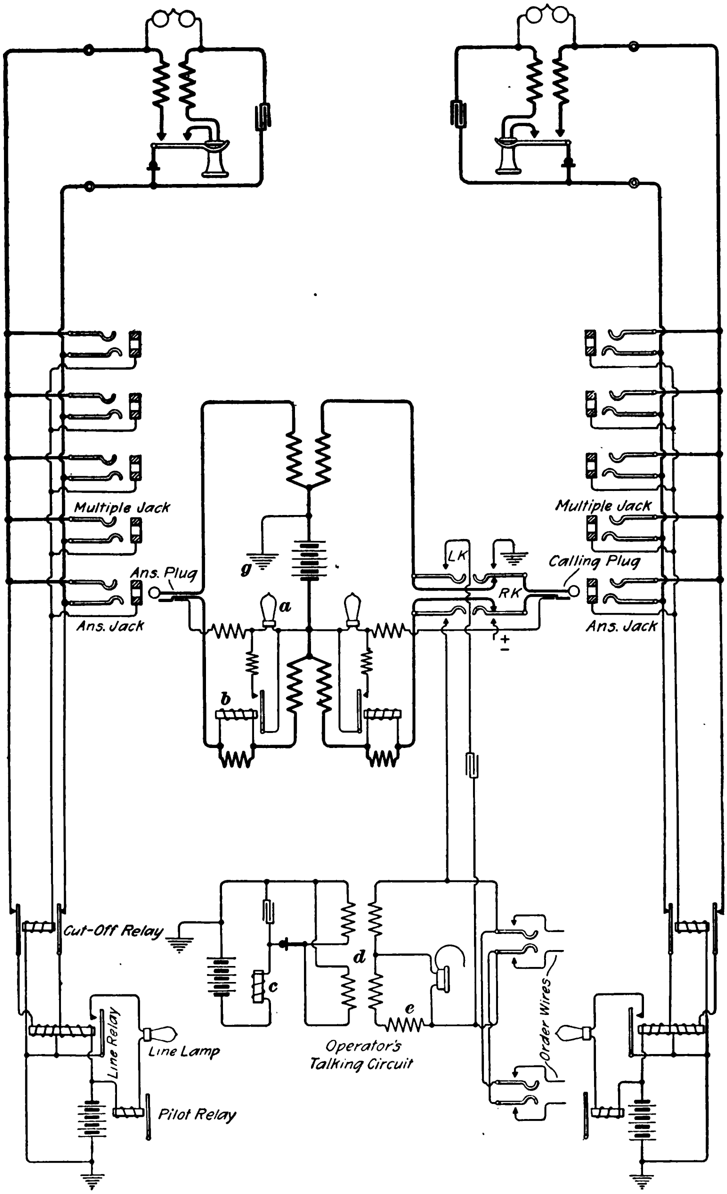

Multiple Jack
Multiple Jack
Ans. Plug
Calling Plug
LK
RK
Ans. Jack
Ans. Jack
g
a
b
+
−
Cut-Off Relay
Line Relay
Line Lamp
Pilot Relay
c
d
e
Operator's Talking Circuit
Order Wires

FIG. 21

36. Operation of Combined Circuits.—In Fig. 21 a cord circuit, such as just described, is shown between two line circuits, such as represented in Fig. 19. Either line, say the one at the left, may be the calling line. When the receiver on the calling line is lifted, a circuit is completed through the line relay and both the line lamp and the pilot lamp glow. The pilot-lamp circuit is not shown. The operator inserts the answering plug in the answering jack and throws her listening key *L K*. The plug causes the cut-off relay to be energized, thus putting out the signal lamps; at the same time, the sleeve contacts of all the multiple jacks of this line are connected with the live side of the battery. The listening key places the operator in communication with the calling subscriber. The supervisory lamp *a* does not glow because it is shunted by a resistance on account of the excitation of the supervisory relay *b*, as previously explained.

37. On learning the line desired, the operator touches the tip of the calling plug to the sleeve of a multiple jack of that line. If the line is in use, the sleeve touched will be in connection with the live side of the battery through the sleeve contact of the plug already in use, which connects the sleeves of all of the multiple jacks to the live side of the battery through a supervisory lamp. Electricity will then flow through the tip of the plug–the tip side of the cord–the calling tip winding of the repeating coil–to ground at *g*. This current will cause a slight click in the operator's receiver, and she will advise the calling subscriber that the line is busy. If no click is heard when this busy test is made, the operator inserts the calling plug in the jack and throws the ringing key. Inserting the plug causes the cut-off relay of the called line to operate and connects the sleeves of all the multiple jacks of this line with the live side of the battery through the sleeve contact of the plug and the supervisory lamps. Throwing the ringing key signals the called subscriber.

38. Until this subscriber's receiver is lifted, the supervisory lamp associated with the calling plug glows, the lamp being in the circuit between the live side of the battery and the ground through the jack sleeve and the cut-off relay. Lifting the receiver, however, establishes a circuit through the ring side of the cord including the supervisory relay and the subscriber's transmitter. The supervisory relay operates to close the shunt around the lamp, which ceases to glow until the receiver is replaced on the hook. While the two lines are connected and both supervisory lamps are out, the operator knows that the connection is still desired; but when both these lamps again light, she knows that both receivers have been hung up and that the connection may be taken down.

39. Operator's Talking Circuit.—The operator's talking circuit shown in Fig. 21 is one of many variations installed on different No. 1 boards. The battery connection to the operator's transmitter is through an impedance coil *c* and through the two primary windings of an induction coil *d*, these windings being in multiple with each other. A condenser is bridged around the transmitter and these two primary windings. The primary circuit partakes of local-battery action, the transmitter setting up current fluctuations in the local circuit formed by the condenser, the two primary windings, and the transmitter. The two secondary windings are in series with each other; the operator's receiver is connected across only one of them and is in series with a non-inductive resistance *e*. This method of connection is for the purpose of reducing the side tone of the operator's set, giving the name *anti-side-tone operator's set*. Incoming voice currents from a station connected with the cord circuit pass mainly through the one secondary winding and the operator's receiver, rather than through the two secondary windings in series, because of the resistance *e* in series with the other winding.

40. Two keys that serve to make connections with *call circuits*, or *order wires* are associated with the operator's circuit, Fig. 21. These wires lead to the head receivers of B operators in multi-office exchanges and afford the means by which the A operators designate to the B operators the number of the subscriber with whom the B operator is to make the final connection in case of a trunked call.

41. Trunk Circuits.—An A operator must deal with two classes of connections, local and trunked. She completes alone all local connections, and refers connections that cannot be completed at her board to a B operator, who attends only to trunked connections.

42. In order to economize the time of B operators in large exchanges, arrangements are such that when connections are made with a line and the ringing key depressed by a B operator, the called subscriber's signal sounds periodically until the receiver is taken off the hook. This act causes a magnet associated with the ringing key to be energized and the ringing key is tripped automatically. In some cases the B operator's cord circuits have no ringing keys; that is, they are *keyless* trunk circuits. The act of inserting the plug of such a trunk in a jack starts the periodic ringing, which ceases only when the called subscriber's receiver is lifted or the plug removed from the jack.

43. The complete circuits involved in making connections through two offices and a trunk circuit between two subscribers are shown in Fig. 22. The subscribers' lines are shown at the extreme right and left; the vertical open space in the center represents space occupied by the trunk and other connections between offices, which may be miles apart. The A operator's cord circuit is shown at the left of this space and the B operator's cord circuit, or the *incoming trunk*, at the right. The outgoing trunk jacks are multiplied through the *A* board, and the sleeve of each jack is connected to the ground through a resistance coil, thus affording a path for the current that lights the supervisory lamp when the calling plug is inserted in an outgoing trunk jack.

44. The B operator's cord circuit is somewhat complicated, as it must furnish talking current and ringing current for the called subscriber's line, provide for automatically stopping the ringing when the subscriber responds, and provide for placing the supervisory relay of the A operator's cord under the control of the called subscriber.

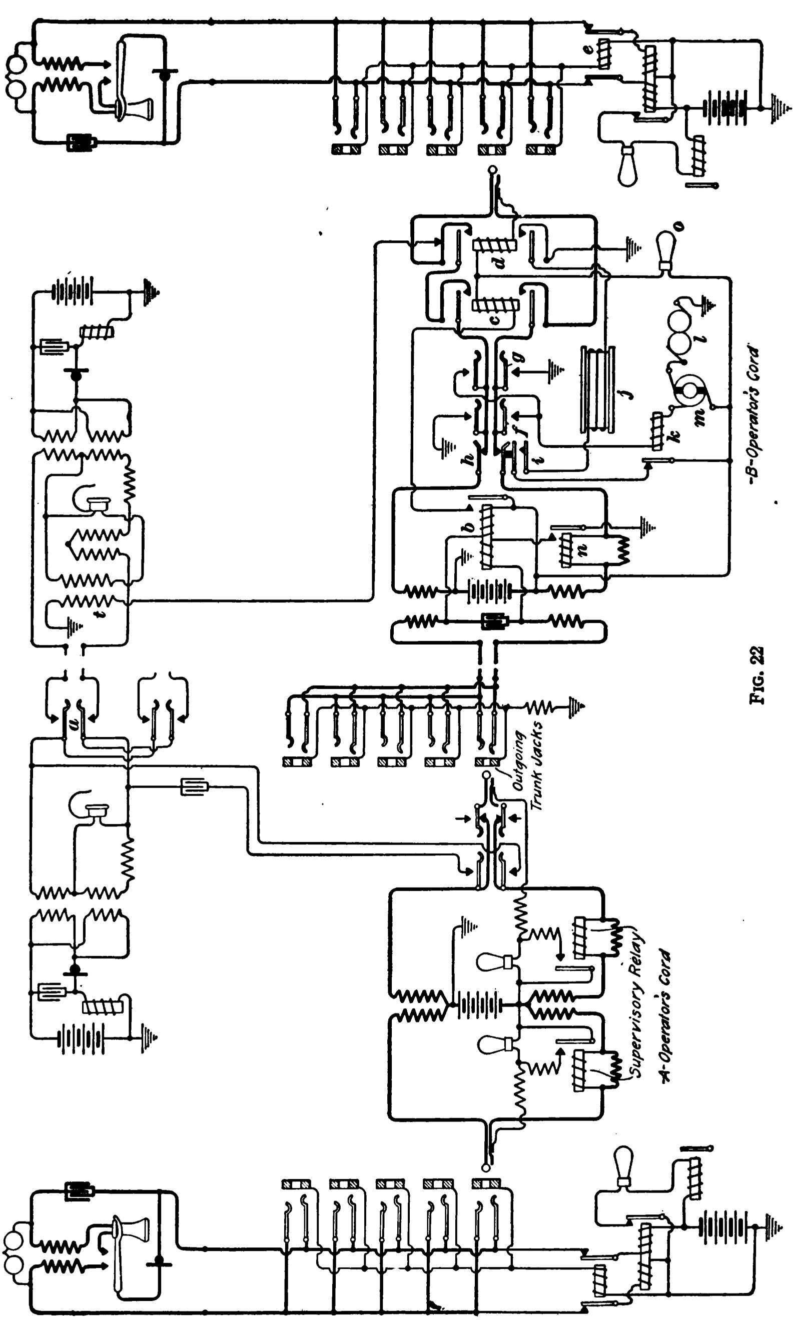

a
t
b
c
d
e
f
g
h
i
j
k
l
m
n
o
Outgoing Trunk Jacks
Supervisory Relay
A-Operator's Cord
B-Operator's Cord

FIG. 22

45. **Trunk Operation.**—The subscriber at the left, Fig. 22, calls the A operator and advises that connection is desired with the station shown at the right. The A operator presses an order-wire key *a* that connects her set with the order wires leading to the B operator's set at the other office and states to the B operator the number desired by the calling subscriber. The B operator replies by stating the number of the trunk to be employed, she knowing at a glance just what trunks are available. Both operators then complete the connections, the A operator by plugging into an outgoing jack of the trunk designated, and the B operator by inserting the terminal plug of the same trunk into a jack of the called subscriber's line, first applying the busy test by touching the jack sleeve with the tip of the plug. If the line is in use, the potential of the sleeve is such that a current is set up through the back contact of relay *d*, which is normally closed, and the tertiary winding *t* of the operator's induction coil, thus causing the busy click.

46. By plugging into the outgoing jack, the A operator places her calling supervisory lamp in a circuit between the live side of the battery and the ground through the jack sleeve, and the lamp glows. This act also closes a path from the live side of the battery through a winding of relay *b* in the B operator's cord circuit and the tip strand of the cord to ground; relay *b* then holds its contact closed.

When the trunk plug is inserted in the called subscriber's jack, a circuit is completed from the battery through the closed contact of relay *b*–the coils of relays *c* and *d*–the sleeve of the jack–and the cut-off relay *e* to the ground. The contacts of relays *c* and *d* close the connections in the B operator's cord circuit between the battery and the called subscriber's line, and at the same time the cut-off relay *e* opens the normal connection of this line with the battery.

47. Having inserted the trunk plug into its jack, the B operator throws one of the two ringing keys *f* or *g*, which, in this case, are arranged for selective ringing to call either of two parties on the line. Throwing either key moves a pair of

contact springs *h* to open the trunk circuit back of the ringing keys and closes a contact *i* in the circuit of the magnet *j* that holds the key in the ringing position. The circuit of this holding magnet is now complete from the battery through the back contact of the relay *k* (normally closed)–contact *i*–magnet *j*–closed contact of relay *d*–ground.

48. Ringing current from the generator *l* is set up in the path through the commutator *m*–relay *k*–ringing key–trunk and line circuits, including the subscriber's ringer–back to ground at the key. This ringing current is periodically interrupted by the commutator, which is geared to the generator shaft and revolves at the speed necessary to ring the subscriber's bell at intervals. This ringing current is not strong enough to open the contact of relay *k* until the called subscriber's receiver is lifted; the contact then opens the circuit of the holding magnet *j* and the ringing key returns automatically to its normal position.

49. If the receiver is lifted during an interval when the ringer is not sounding, current is set up from the battery through a third brush on the commutator–relay *k*–ringing key–cord and line circuits–back to ground at the key, and this current opens the contact of relay *k* and causes the ringing key to be released so as to prevent unnecessary ringing.

50. Relay *b* cannot act until the A operator plugs into the trunk jack, and until this relay acts, relays *c* and *d* cannot close the incoming trunk circuit; hence, no circuit for ringing current to the subscriber's station can be complete until the A operator selects the right trunk jack.

51. When the receiver at the called station is lifted, battery current is set up in the incoming trunk circuit and the subscriber's line. This current causes relay *n* to close a circuit that grounds the ring side of the trunk, completing a path from the battery to the ground through the A operator's supervisory relay. The latter relay then closes the shunt around the supervisory lamp, which becomes dark, thus informing the A operator that the called subscriber has responded. When

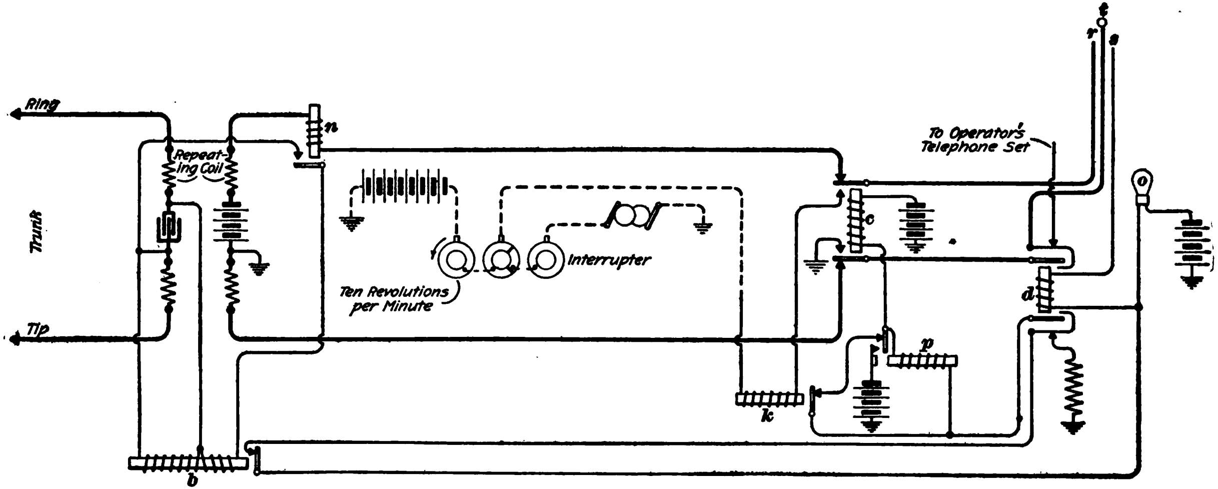

Ring
Trunk
Tip
Repeating Coil
n
b
Ten Revolutions per Minute
Interrupter
k
c
p
d
To Operator's Telephone Set
r
t
s
o

FIG. 23

this subscriber's receiver is hung up, relay *n* opens the circuit of the A operator's supervisory relay and the associated lamp relights. Thus the supervision of the call reverts to the A operator the same as when all the connections are made at the one switchboard.

52. **A trunk disconnect lamp** *o* in the B operator's cord is in a circuit that is closed when the plug is in a jack. While this cord circuit is in use, however, the disconnect lamp is shunted by a circuit from the battery through the closed contact of relay *b* and the coil of relay *c*; the lamp therefore remains dark. When the A operator's plug is withdrawn, this shunt circuit is opened by the deenergizing of relay *b* and the lamp lights, thus informing the B operator that the connection may be taken down.

53. **Keyless Trunk.**—Fig. 23 shows the circuits of the keyless incoming trunk used with the standard No. 1 relay switchboard. The ring, tip, and sleeve contacts of the plug are represented at *r*, *t*, and *s*, respectively. Relays *b*, *c*, *d*, *k*, and *n* correspond to the relays similarly lettered in Fig. 22. The several batteries indicated show merely different connections to the same 24-volt battery, except that the interrupter is connected with a 48-volt supply.

54. When the A operator plugs into an outgoing trunk jack the battery voltage is applied to the trunk wires and to the terminals of the high-resistance winding on relay *b*, Fig. 23; the contact of this relay therefore closes, placing lamp *o* in a circuit between the battery and the ground, and the lamp lights.

55. When the B operator plugs into the subscriber's jack a circuit is completed from the battery through the lamp and relay *d* to the sleeve contact of the plug and thence to the ground, as in Fig. 22, causing the contacts of relay *d*, Fig. 23, to close. This act places the coil of relay *c* in shunt with lamp *o*, the circuit being through the back contacts of relays *p* and *k* and the closed contacts of relays *d* and *b*. This shunt around the lamp extinguishes the light, and at the same time the operation of relay *c* opens both cord conductors and connects the ringing generator across the subscriber's line. The interrupter causes periodic ringing. The circuit of the ringing current includes the coil of relay *k*, but the current is not strong enough to operate this relay.

56. When the subscriber's receiver is lifted, the current from the ringing generator—or from the battery, according to whether the receiver is lifted while the bell is ringing or not—causes the contact of relay *k* to open the circuit around relay *p*. Current is thus diverted through relay *p*, causing its contacts to close and shunt relay *c* out of the circuit. The contacts of relay *c* now drop back, cutting off the ringing current and closing the cord circuit.

57. Establishing the cord circuit through the subscriber's receiver causes relay *n* to close the circuit through the low-resistance winding of relay *b*, and the current thus set up in the trunk circuit operates the A operator's supervisory relay, Fig. 22, and extinguishes her supervisory lamp. When the subscriber's receiver is hung up, the contact of relay *n*, Fig. 23, opens and the A operator's supervisory lamp relights.

58. The act of hanging up the subscriber's receiver cannot cause renewed ringing, because the ringing relay *c* is shunted out of circuit by relay *p*. This relay remains in shunt with lamp *o*, preventing its illumination until the A operator withdraws the calling plug from the trunk jack. Relay *b* is thereby deenergized and its contact opens the circuit of relays *p* and *c*, thus allowing lamp *o* to relight and inform the B operator that the connection can be taken down.

TERMINAL APPARATUS

59. Important adjuncts to the switchboard are the various arrangements for terminating the wires and cables. These arrangements consist chiefly of a *main distributing frame* (M. D. F.), an *intermediate distributing frame* (I. D. F.), and the protective devices associated with the main frame to prevent damage, which might otherwise arise from foreign currents.

The distributing frames and protective devices in large exchanges are mounted in a separate room from the switchboard, or operating, room; associated with them are also the various other frames, or racks, carrying the line and cut-off relays, repeating coils, and other parts of the apparatus that are not carried on the switchboard itself.

MAIN FRAME

60. The **main distributing frame** is an iron framework carrying two sets of contacts by which the circuits entering the office from outside are connected with the circuits leading to the switchboard. One set of contacts is on each side of the frame; *jumper wires*, usually consisting of twisted pairs of rubber-covered wires, serve to make the proper cross-connections between the two sides. These jumper wires are run through channels and rings in the framework in a systematic manner. They are in the nature of temporary links between the inside and the outside lines and afford a means for changing the connection of any outside line with any switchboard line.

61. The main distributing frame may range in size from one or two short vertical bars carrying the groups of line and switchboard terminals, as in a small office, to a very elaborate affair, consisting of vertical, or vertical and horizontal, bars carrying the terminals for many thousand inside and outside lines. When speaking of the lines at the main frame, that portion of the line extending from the main frame to the subscriber is commonly called the *outside line*, and that portion extending from the main frame to the switchboard, the *inside*, or *switchboard, line*.

Since the main distributing frame is the first point in the office where the line wires emerge from the sheaths of their cables and appear as individual pairs, it is the logical place to mount the devices for protecting the central-office equipment against the damaging effects of extraneous currents.

62. The general appearance of a small main frame associated with a one-position magneto switchboard is shown in

Fig. 24. In this frame there are two vertical strips, one supporting the terminal apparatus of the outside lines and the other the terminal apparatus of the inside lines. Facilities for cross-connecting between the inside and the outside lines are provided by the distributing rings on the back of the frame, the pair of jumper wires being soldered to the terminals of any inside line and then run through these rings to the terminals of the outside line.

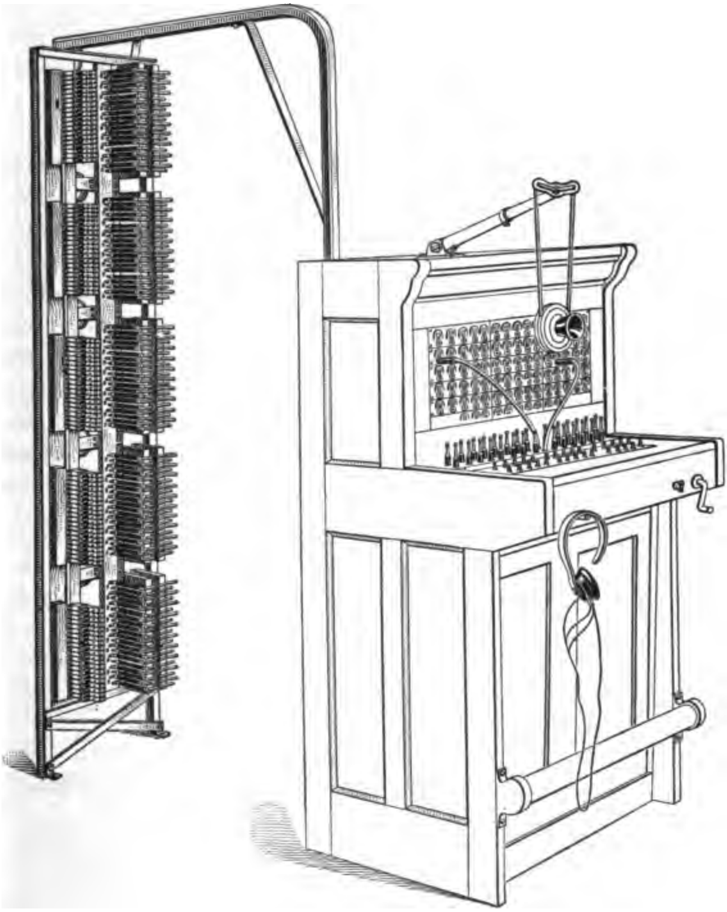


Fig. 24

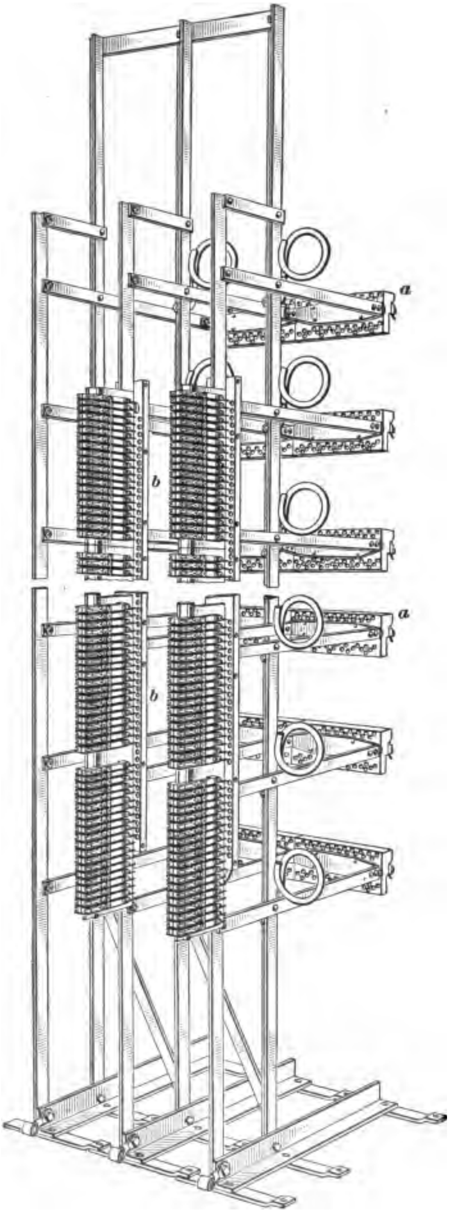


Fig. 25

When a line cable is installed in a distributing frame such as shown in Fig. 24, it is run either upwards from the floor or downwards from the ceiling, its wires being fanned out to make contact with the various line terminals, as will be described later. Similarly, the switchboard cable, when installed, passes along the curved rack from the switchboard to the top of the frame, and thence down to the switchboard terminals on the frame, this cable being fanned out in the same manner.

63. In Fig. 25 is shown a section of a larger main frame, known among Bell companies as the A type. Terminals arranged in horizontal rows *a* are provided for connecting the outside cables, and on the opposite, or switchboard, side are terminals in vertical strips *b* for receiving the cables from the switchboard and other portions of the central-office equipment. These vertical strips carry the arresters. In the later B type frames this arrangement is reversed, the line cables terminating on the vertical strips that carry the arresters, and the switchboard cables terminating on the horizontal strips.

MAIN-FRAME PROTECTION

64. Two protective devices, usually mounted together, are furnished for each line, an air-gap arrester and a heat coil, the names *open-space cut-out* and *sneak-current arrester* also being used. Fig. 26 shows such a combination, and Fig. 27 shows the theory, the parts being lettered alike in both illustrations. The air-gap arrester is like those used for station protection, namely pairs of carbon blocks separated by thin sheets of mica so as to form air gaps *a*. High-potential currents entering by way of the line conductors *b* escape to ground across these gaps.

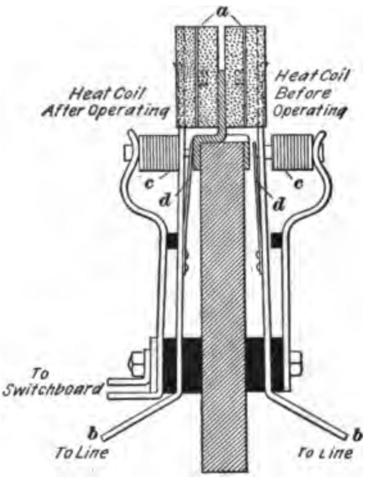


Fig. 26

65. The heat coils afford protection from injury that might be caused by long-continued low-potential current. Coils *c*, Figs. 26 and 27, of fine German-silver wire surround brass cores inside which loosely fitting brass pins are soldered. A continued current large enough to endanger the other apparatus causes heat enough in the coil to melt this solder, and a spring *d* then forces a contact against

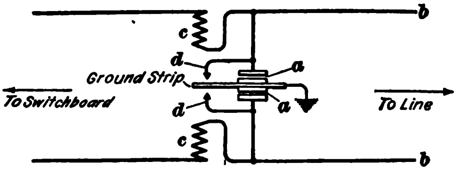


Fig. 27

the ground strip, as is shown by one contact in Fig. 26, allowing the current to escape harmlessly. Fig. 28 shows ten of these combined protectors mounted in a single strip.

INTERMEDIATE DISTRIBUTING FRAME

66. The chief function of the intermediate distributing frame is to provide a means for changing the connections of answering jacks and their associated relay apparatus so as to equalize the work of operators. Structurally, the intermediate frame resembles the main frame, but it is without protective devices. On opposite sides are strips of terminals between which connections are made by means of three-wire jumper cables. Fig. 29 shows the complete circuit connections of one line, these connections being the same as shown in a more abbreviated form in Fig. 19. The line enters the main frame at *a*, Fig. 29, through which it passes by two-wire jumpers *b*, thence continues to terminals *c* and *d* on the intermediate frame and from there to the tip and ring springs of the multiple jacks. The sleeves of the multiple jacks are connected with a third terminal *e* on the intermediate frame. By means of a three-wire jumper cable, this set of multiple jacks can be cross-connected with the terminals of any answering jack and its associated apparatus, which are permanently connected as a unit, so that this line can be placed under the care of any operator.

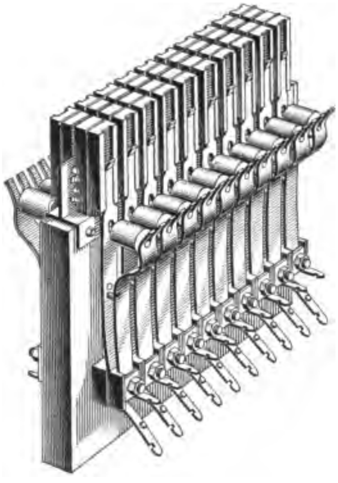


FIG. 28

67. The number of calls originating on different lines is not uniform. Some operators can therefore attend to more answering jacks than others. The average number of such jacks for each operator is not far from 100 in large exchanges; but if the lines are especially busy the number must be reduced to perhaps 30, and if they have few calls per line an operator may be able to handle 200. The intermediate frame affords a means of redistributing the work from time to time as may seem necessary.

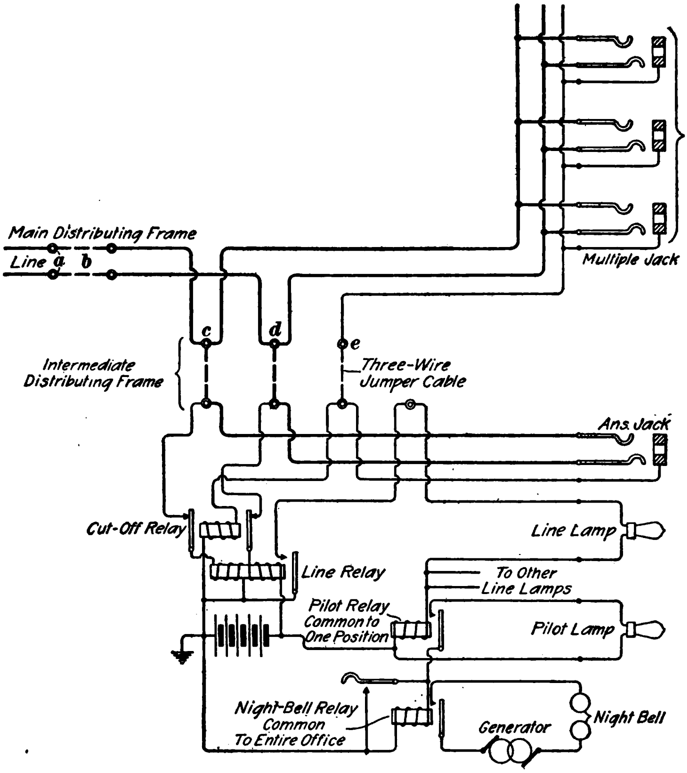


FIG. 29

68. In some small exchanges, the main and intermediate frames are sometimes combined in a single structure. The multiple jacks are then wired to the protectors on one side of the frame; the outside lines and the answering jacks are brought to the other side, the usual arrangement being with the line terminals on the lower half of the frame and the jack terminals on the upper half.

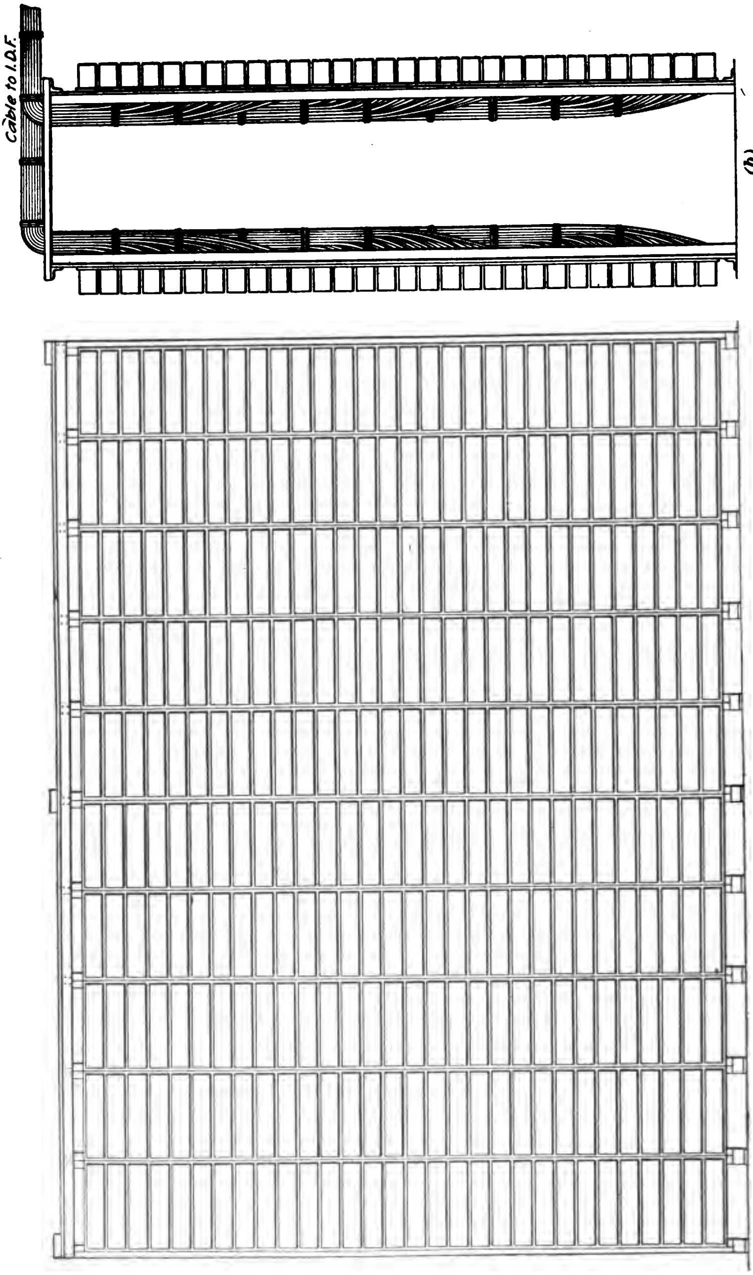


FIG. 30

RELAY RACKS

69. In order not to crowd the cabinet of the No. 1 relay switchboard, the relays are mounted on a separate rack in the terminal room, the arrangement of relays being as shown in Fig. 30, in which view (*a*) shows the front and view (*b*) a section. In a large office this rack and the two distributing frames are usually arranged side by side and parallel, the intermediate frame being midway between the main frame and the relay rack. This plan is not always followed, however.

CENTRAL-OFFICE WIRING

SWITCHBOARD WIRE AND CABLE

70. A large multiple board may have thousands of circuits such as shown in Figs 19 and 29, and a correspondingly large number of cord, trunk, and other types of circuits. The principles of these circuits have been described and illustrated, but no conception of the arrangement of conductors in connection with a switchboard has been given. The great number of conductors must be arranged compactly and systematically. The two wires of each circuit must be close together and must be twisted to prevent inductive disturbances. As many as thirty or forty thousand wires must sometimes be bunched together in a run from one part of a central office to another. The insulation must be perfect, inductive disturbances must be minimized, the wires must be accessible for repairs and must be protected as well as possible from damage by fire, water, and mechanical movements. The problem of central-office wiring is a difficult one on account of space restrictions imposed by the small size and close crowding of apparatus units, such as signal lamps, jacks, relays, etc.

71. **Switchboard wire** is the name applied to the conductor used in central-office work for all purposes except where there is special need for extra-heavy insulation, as in the case of power wires, wires carrying large currents, and ringing-current leads. Switchboard wire is usually No. 22 B. & S. gauge copper that is tinned, then wrapped with one or two layers of silk and covered with a wrapping of cotton. These wires are used singly, or twisted together in pairs.

72. Switchboard telephone cables consisting of single wires or twisted pairs, or both combined, are made for use where many circuits are to follow the same route for some distance. In **factory-made cables,** the bundle of insulated wires is covered by a protective sheath, as shown in Fig. 31. This sheath consists of an inner wrapping *a* of thread, a layer *b* of manila paper, a layer *c* of lead tape, another layer *d* of paper, a second layer *e* of thread, and an outer braiding *f* of cotton. The outer braid is impregnated with a heavy coat of gray fireproof paint. Frequently, for the purpose of economy in space, in one direction, it is necessary to flatten such cables, and a cable so treated is shown in Fig. 32.

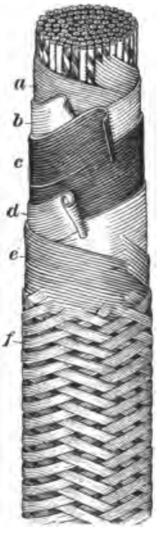


FIG. 31

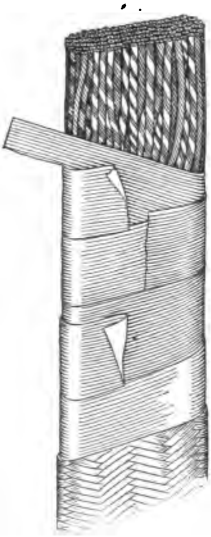


FIG. 32

COLOR CODE

73. The outer cotton cover of switchboard wire usually has a distinctive color or combination of colors, based on the colors blue, orange, green, brown, and slate, in the order named. The standard 20-wire code is as follows:

Blue
Orange
Green
Brown
Slate
Blue-white
Blue-orange
Blue-green
Blue-brown
Blue-slate
Orange-white
Orange-green
Orange-brown
Orange-slate
Green-white
Green-brown
Green-slate
Brown-white
Brown-slate
Slate-white

In large cables, each pair consists of a wire of the foregoing code and a wire of some other distinguishing color, as red, white, black, red-white, and black-white. As each of the latter colors and its combination with a code wire serves to distinguish one of twenty pairs, one hundred different pairs with distinguishing colors may be combined in one cable.

74. So-called **hand-made cables** are used where a number of wires run parallel for short distances with occasional departures from the groups. Such cables are laid up and sewed together by hand as indicated in Fig. 33, which shows a hand-made cable on the under side of a switchboard keyboard, the keyboard being in this case raised to expose the wiring. If the large number of wires necessary to connect with the various key contacts were not grouped together and arranged systematically, as shown in this figure, the result would be what is commonly termed a rat's nest, meaning an inextricable tangle of wires. A cable such as that shown in Fig. 33 provides for the systematic and neat arrangement of the wires, and also by means of a *knee*, or bracket, located at the right behind the turn, it permits the raising and lowering of the keyboard without placing any of the wires under undue strain. Such cables are not provided with an outside sheath or braiding, but are laced into position with cord and afterwards shellacked to keep out moisture.

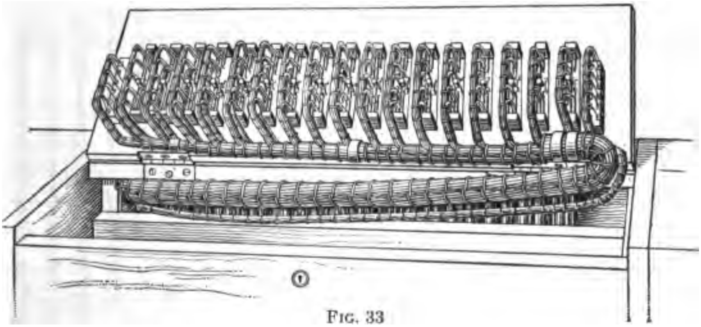


FIG. 33

75. The wire used for power circuits and for the leads of ringing generators is insulated with a good grade of rubber compound, as is the case wherever heavier insulation is required than that afforded by silk and cotton insulation. This compound is usually covered with an outer single or double protecting braiding of cotton, sometimes impregnated and sometimes dry.

FORMING FACTORY CABLES

76. The terminals of jacks, relays, resistances, signal lamps, etc. in a telephone-exchange office are necessarily close together and are usually arranged in rows corresponding to the devices with which they are connected. The wires of the switchboard cable used to connect with these terminals must be removed from their sheath and laid out in a systematic manner for making the connections. The process of arranging these wires is called *fanning out*, or *forming*, the cable, and the appearance of a cable thus formed is shown in Fig. 34; it gradually diminishes in size as each wire or small group of wires leaves it.

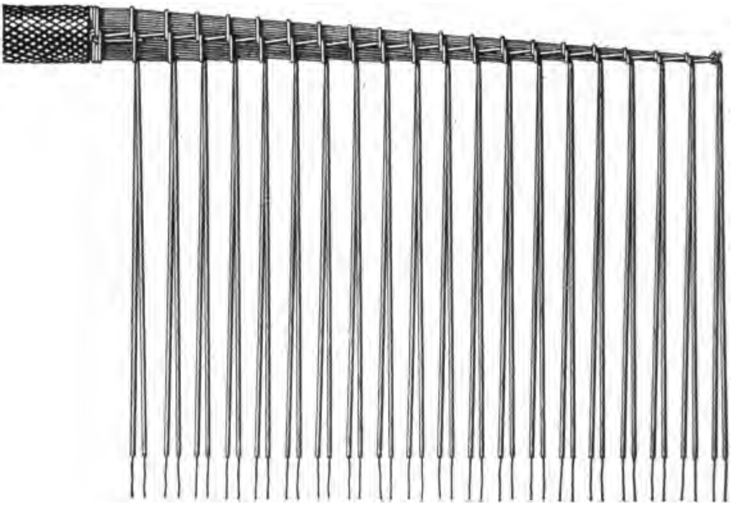


FIG. 34

77. The process of forming a cable is as follows: First, the sheath of the cable is removed for the required distance, this distance being such as to allow somewhat more than

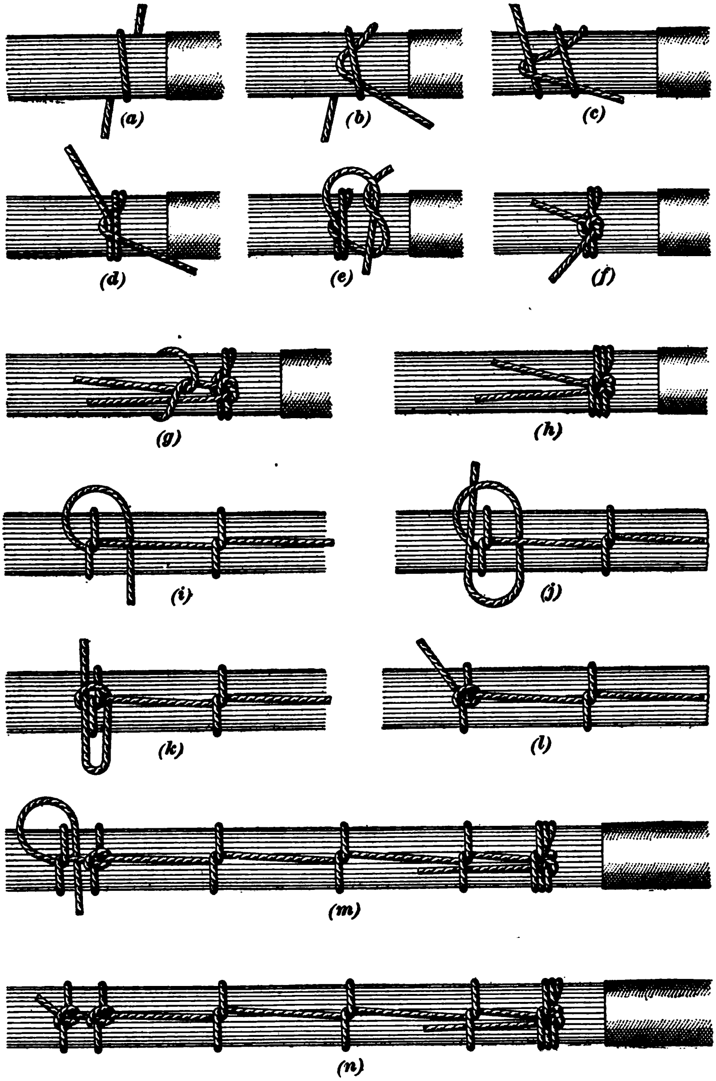


Fig. 35

sufficient wire to reach the most remote terminals. At the butt, or end of the cable insulation, the outer serving of large cables is cut and tucked in and on small cables it is simply trimmed off evenly all around. The entire exposed end of the cable is then immersed in boiling beeswax to prevent the insulation from fraying while being handled and also to prevent the absorption of moisture. The cable is now ready for lacing and forming.

78. The various operations of lacing are shown in Fig. 35. The lacing is done with a good grade of linen twine, thoroughly boiled in beeswax. The successive stages of lacing a length of exposed cable wires beyond the butt are shown in the various views, which are self-explanatory. In making such a form as shown in Fig. 34, one pair of wires would be taken out after each successive stitch in the lacing. To facilitate doing this, at regular intervals nails are driven into a board the desired distance apart, the cable being laid parallel to the nails and a pair of wires being drawn off at right angles after passing each nail.

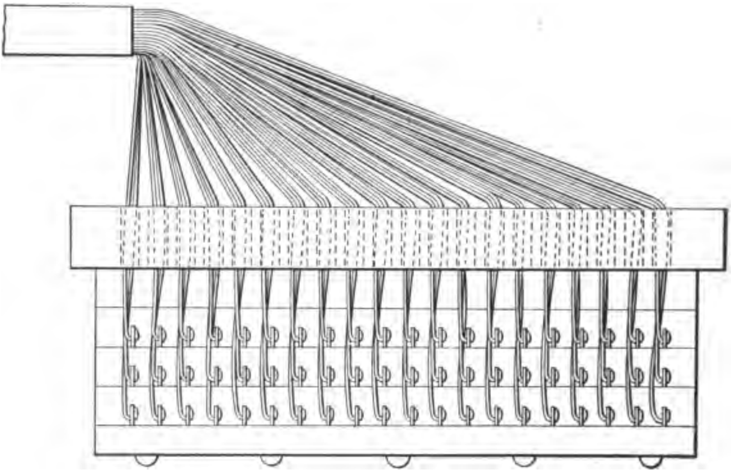


FIG. 36

79. If the apparatus is readily accessible or can be withdrawn with the cable for repairs, the cable can be formed near the strip of terminals, as shown in Fig. 36. The best example of this practice is on main and intermediate distributing frames.

Frequently, however, a small degree of flexibility must be allowed between the cable and the apparatus, in which case the cable is formed a considerable distance back from the terminals, the wires leading from it to the terminals being made sufficiently long to permit the desired flexibility. The individual wires, leading from the cable proper to the terminals, are called *skinners*, and reference is made to *short-skinner* forms and *long-skinner* forms, according to the length of the skinners.

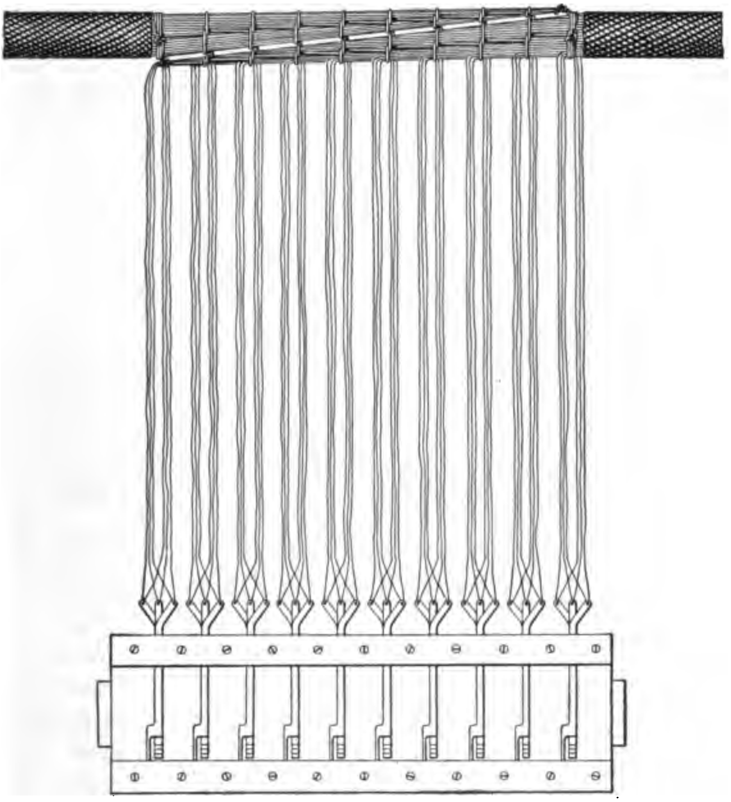


FIG. 37

The long-skinner form permits withdrawal of a strip of jacks without disturbing the cable to any great extent. The most familiar example of long-skinner practice is in the case of

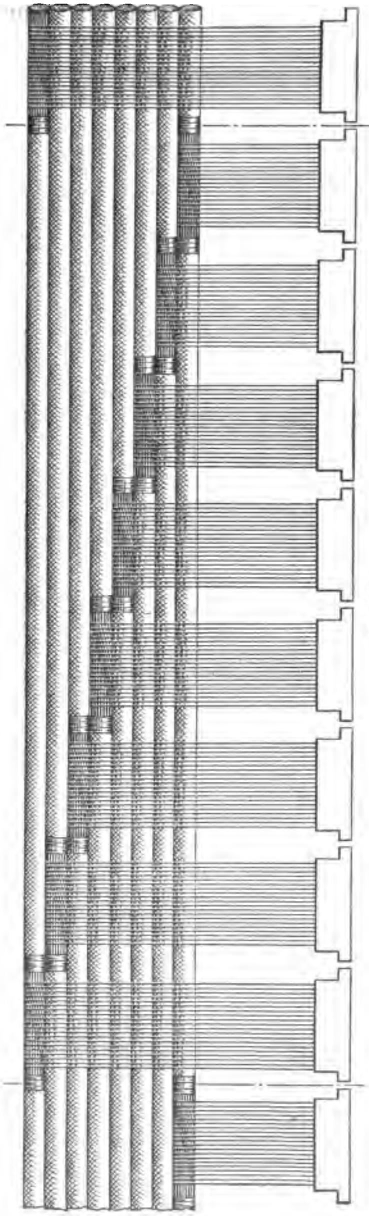


FIG. 38

multiple jacks. In multiple-jack work, however, except at the ends of the run, two cables enter each jack strip, making two skinners for each jack terminal. The method of doing this is shown in Fig. 37; two forms are tied together so that they taper in reverse directions and form virtually a mass of uniform cross-section.

80. Fig. 38 is a diagrammatic plan view of a single horizontal row of jack strips with connections leading to the cables behind the switchboard. The board is of the eight-panel type, having eight strips of jacks in each horizontal row of each section. The cables are arranged in layers, only one layer appearing in the illustration. The skinners for the first strip of jacks are taken from the cable nearest the front of the board; those of the second strip of jacks from the second cable; and so on, the skinners of the eighth strip of jacks being made long enough to reach clear through the piled cable to the eighth, or rear, cable in the layer. In all except the first, or front, cable, the skinners pass between the cables of the horizontal layers. This arrangement is repeated in each section of the switchboard and shows how a great mass of connections can be arranged systematically.

81. In order to obtain the most satisfactory multiple, the layers of cable must increase in height at exactly the same rate as the strips of jacks in the board, otherwise the skinners will not lie horizontal, and damage and difficulty in clearing trouble are likely to result. If the cables gain in height more rapidly than the jacks, as is too frequently the case, then the height of the cable determines the capacity of the board, since in that case the cable space is exhausted before the jack space is full. Flat cable, as shown in Fig. 32, is useful in this connection.

FORMING HAND-MADE CABLES

82. The most difficult part in the making of hand-made cables is their proper initial planning, which must often be done in the field. The correctness and neatness of the result depends, in a large measure, on how carefully the work was planned before being executed.

The terminals to be connected by the wires of a hand-made cable often lie in several different planes. This is true of the hand-made cable shown in Fig. 33, where the ringing-key and listening-key terminals on the bottom side of the key shelf lie in a horizontal plane, while the terminals at the other end of this cable, not shown in this figure, lie in a vertical plane. The laying out of a cable, however, must ordinarily be accomplished in one plane, and the workman must make allowance for the bending of the cable from this one-plane position into the actual position that it will occupy when it is in place in the board.

83. Hand-made cables, when of considerable complexity, are usually formed on a large, flat board, covered with a sheet of heavy paper on which the various dimensions and directions may be laid out. At the points at which the various skinner wires will branch off from the bunch, nails and screw hooks are driven through the paper into the board. Such a board, laid out for a rather complex cable, is shown in Fig. 39. The wires are then laid along the paths indicated by the nails, making each

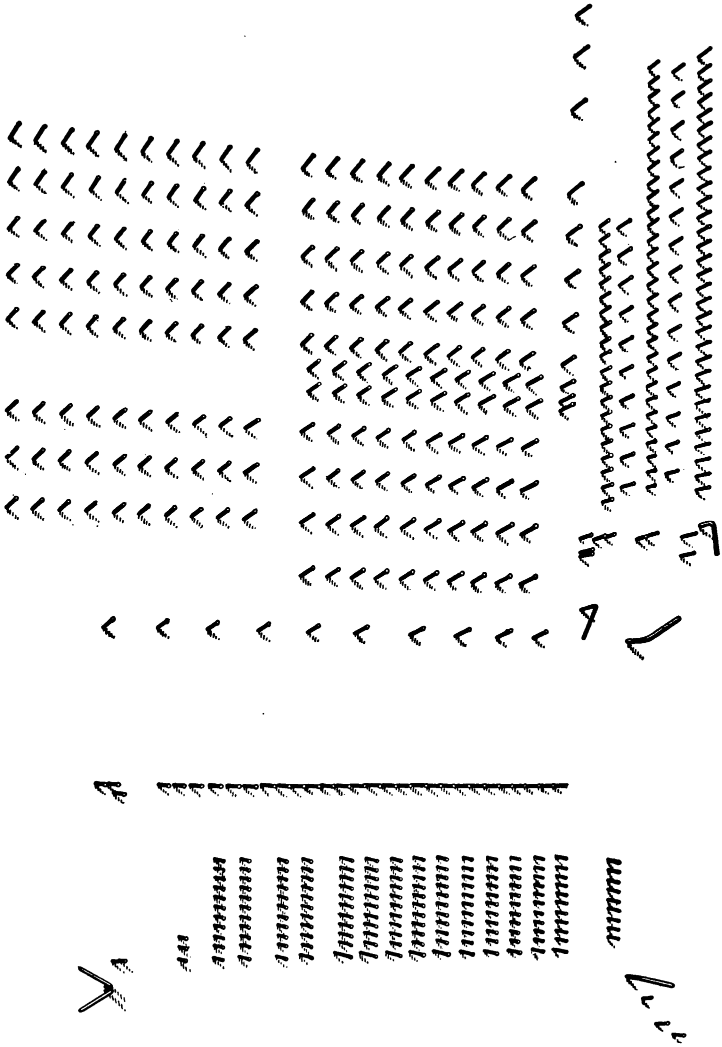


FIG. 39

wire or pair of wires reach from the proper place in one group of terminals to the proper place in another group of terminals, so that all of the conducting paths that will be required will be present and properly located. In doing this, code color wires

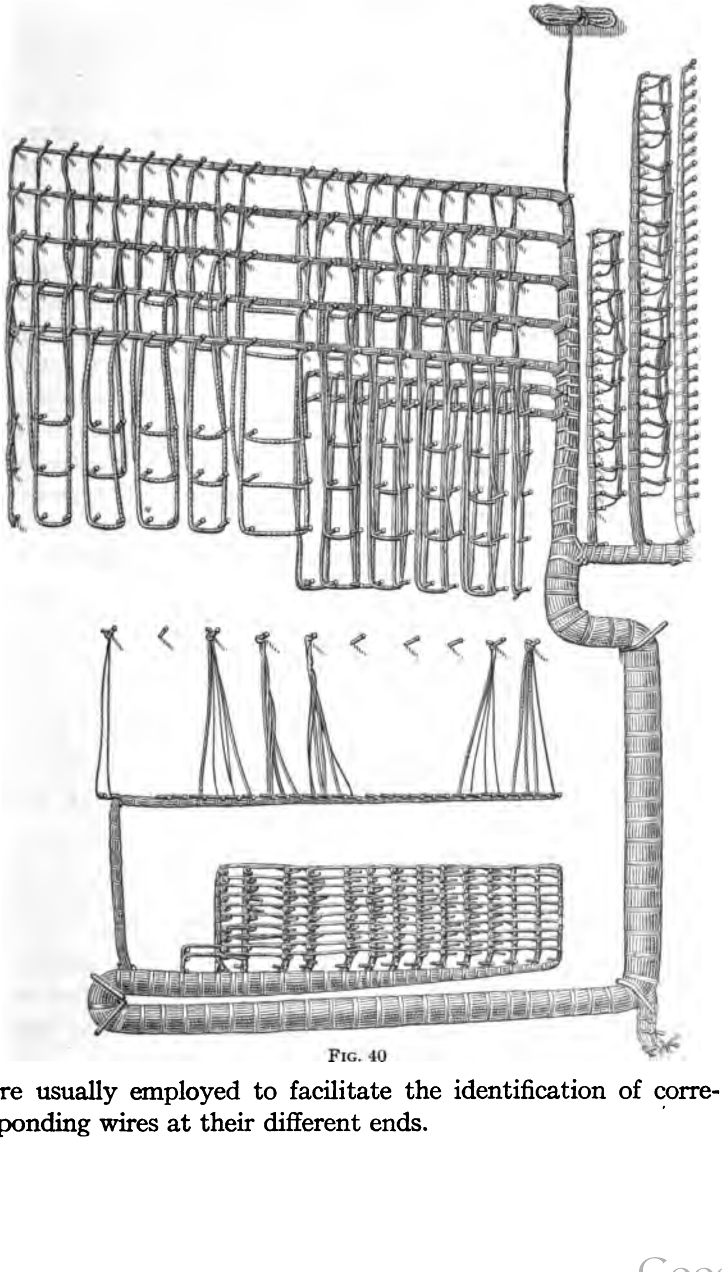


FIG. 40

are usually employed to facilitate the identification of corresponding wires at their different ends.

84. After the wires are in place, the whole layout should be very carefully checked in order to correct mistakes, which might later necessitate undoing the entire work. When the check is completed, the cable is ready for lacing, as shown in Fig. 35. A cable formed on the board shown in Fig. 39 will appear as in Fig. 40. The skinner wires may now be cut loose from the nails and the completed cable removed, leaving the board for the formation of another similar cable. Such cables are made with wire that has been thoroughly impregnated with beeswax.

85. The cable is then placed in the position in which it is to be used, its heavier portions being attached, wherever possible, to structural portions of the switchboard by means of leather straps securing it to the woodwork of the cabinet. In placing it, care should be taken to see that the various skinners will reach their respective terminals in a systematic manner. The various skinners are now stripped of insulation for a short distance from their ends and soldered in place. The board is then tested out to make sure that the proper points are connected and that there are no reversals, opens, or crosses.

SOLDERING AND FINISHING

86. **Soldering** is the most important handicraft of the telephone repair man. The first rule in using soldering tools is that the tip of the copper, or *iron*, as it is called, shall be kept clean and well tinned. By the latter is meant that the surface of the copper shall be kept evenly coated with solder thoroughly united with it. Good work is impossible unless this tinning exists, and it cannot exist unless the copper is kept reasonably smooth and free from corroded spots. From time to time it must be dressed up by filing, and occasionally during use should either be dipped in sal-ammoniac solution for an instant or wiped on a pad of cotton waste saturated with sal-ammoniac solution. This tends to clean off the copper oxides which gather on the metal and thus insulate it from tinning. The copper must be hot when dipped in or wiped on the sal-ammoniac solution, and there should be some solder on the copper at the time; the solder will spread readily all over the surface of the tip when rubbed a little.

87. With a clean, hot copper two pieces of metal already coated with solder can be easily soldered together unless they are so large that they cannot be well heated by the copper. If both parts are tinned or coated with solder, then with a flux of rosin the solder will flow; in telephone work, the solder most commonly used is in a long strip with a core of powdered rosin. Good results cannot be expected in soldering untinned metals together with rosin only, so that it is unwise to use untinned copper wire in connection with switchboard apparatus.

Rosin is the only flux recommended for ordinary telephone work, since it serves its purpose well and does not injure insulation or corrode the metals. A flux composed of 5 parts chloride of zinc, 4 parts alcohol, and 1 part glycerine serves well for untinned surfaces and has less corrosive effect than most other chemical fluxes; this flux can be used for soldering parts that can afterwards be thoroughly washed. But neither this flux nor soldering paste nor soldering sticks should be used to solder telephone conductors.

88. After the cable is soldered in place and tested, any wires that may have become disarranged are straightened and made to present a neat appearance, after which the entire cable is coated with shellac; this stiffens the cable and at the same time aids to exclude moisture. The use of orange shellac or other colored shellacs should be avoided, on account of the alteration it makes in the appearance of the color code wires.

WIRING IN A SMALL CENTRAL OFFICE

89. Fig. 41 shows the back of a two-position magneto switchboard with cables formed according to the foregoing methods. The line cables leading to the jacks and drops are factory made, their ends having been formed to provide individual skinners leading to each drop and jack unit in the upper portions of the board, as shown. Space has been left on the right side of the board (left side as viewed from the rear) for a number of additional drops and jacks. The cables are provided for the full number, and the spare wires are enclosed in fiber tubes for protection.

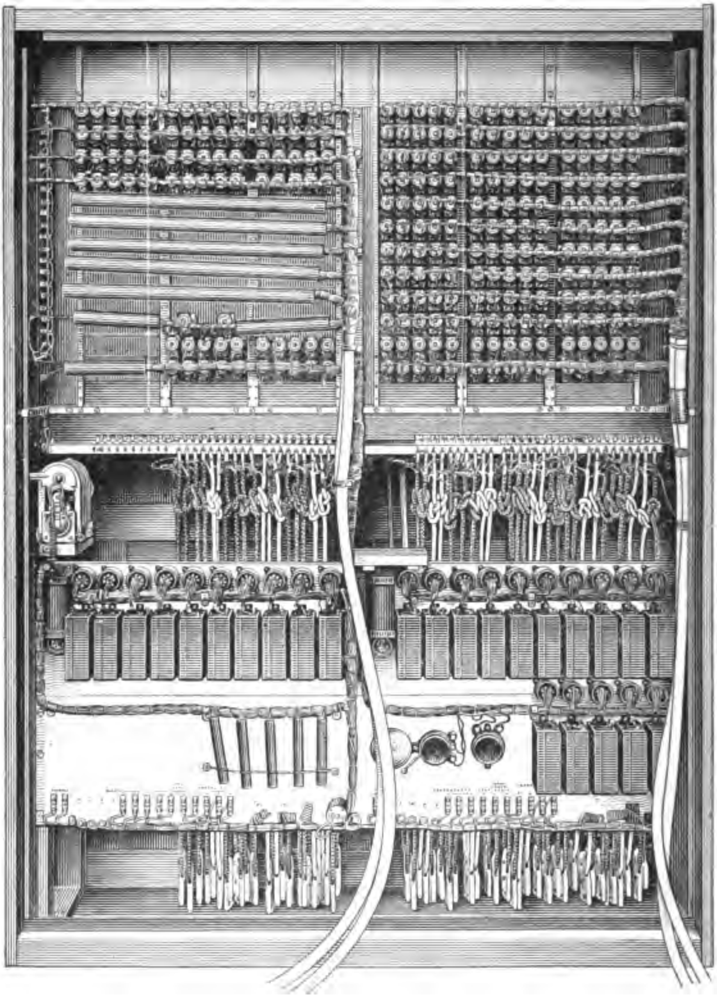


FIG. 41

Just above the level of the cord weights near the bottom of the cabinet, Fig. 41, is shown the connecting rack on which is mounted the various terminals, buzzers, bells, condensers,

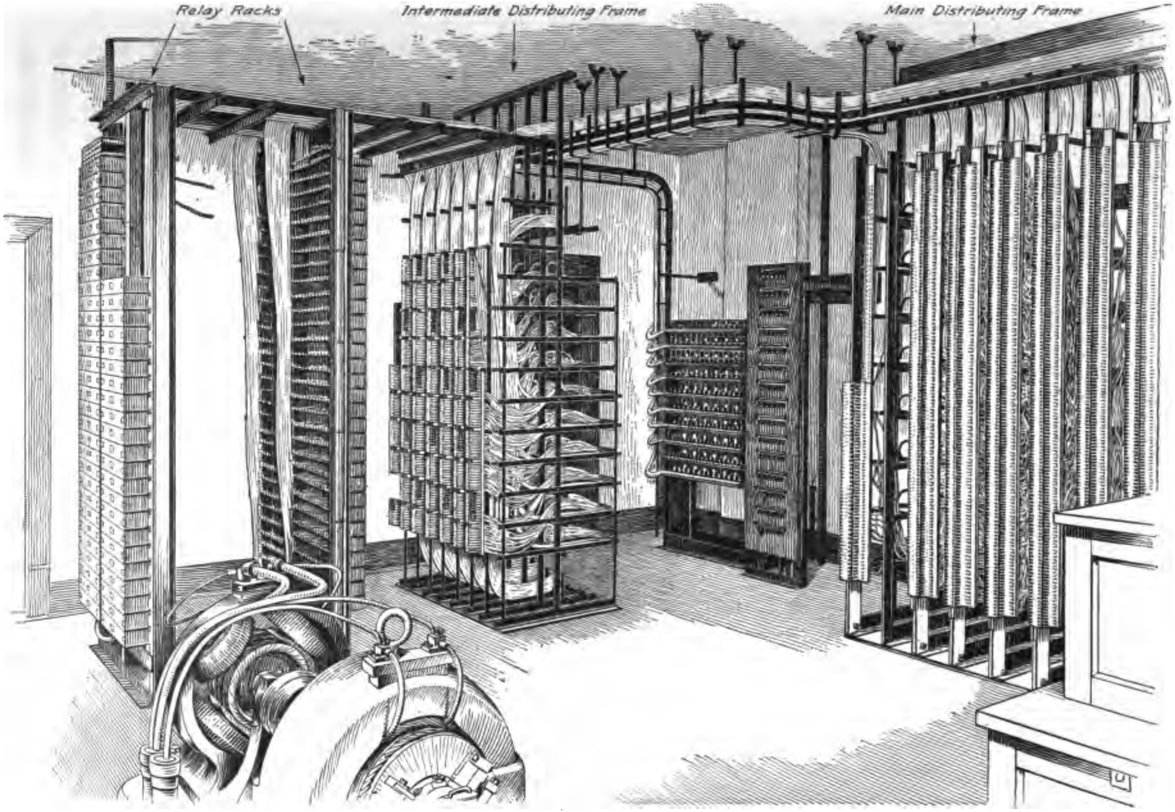

Relay Racks
Intermediate Distributing Frame
Main Distributing Frame

FIG. 42

repeating coils, etc., these being connected by hand-made cables. Above this rack are shown the cords with knots to adjust the lengths so that the weights will not strike the bottom of the cabinet. The stationary ends of the cords are attached to terminals on the cord rack. At the left of the knotted portions of the cords is the magneto-generator.

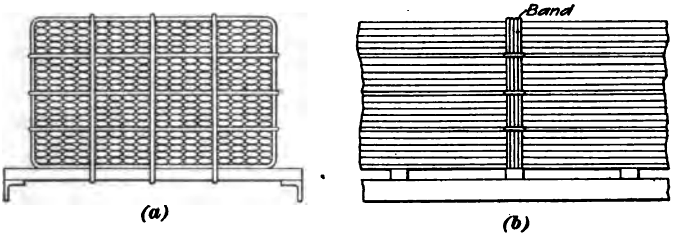
In small boards, such as that just illustrated, there is very little wiring outside of the cabinet. In large boards, however, much of the apparatus is mounted in places other than in the switchboard cabinet, and the wiring extends between the various groups of apparatus sometimes widely separated in the exchange building.

90. The use of hand-made cables in a telephone switchboard is confined to short runs within the cabinet. Long runs, both within and without the switchboard proper, and between the switchboard and the various distributing frames and racks, are wired almost exclusively with switchboard cable formed to suit the requirements of the terminals which the cables are to connect. As a rule, these cables are formed in the factory, the lengths between the formed ends of the cables having been determined by carefully worked out plans. In many cases, however, the installer must form cables or reform those that have been erroneously formed in the factory, and therefore he should be thoroughly familiar with the best practice.

Fig. 42 shows an excellent example of how the cables are carried between the relay racks and different distributing frames in a central-office installation of considerable size. In this case all the cables are run vertically from their various terminal strips to the top of the frames and are thence carried along iron racks supported from the ceiling or from the top of the frames, as indicated. These racks should always be of a substantial nature and the cables on them should be neatly laid and sewed so as to present a systematic and uniform appearance. The orderly arrangement of cables and of the wires leading from them to the other devices in the circuits is the first requisite of good wiring.

CABLE SEWING

91. The cables of a run must be bound together in order to secure them to the rack, or runway. In a horizontal run, the runway supports the weight of the cable, which is secured merely against dislodgment; but in a vertical run the cable must be secured in a way to support its weight also. Several methods of securing cables to runways are in use, a method called the **Chicago stitch** being probably the most common. Fig. 43 (*a*) shows a cross-section and (*b*) a side elevation of a run of 320 cables arranged in 20 layers of 16 cables each and sewed by this method. The cables are fastened, as laid, by a temporary sewing; the bottom layer of cables is sewed to the rack, the next layer to the first, and so on, the stitch being a loop or chain stitch, which, when cut at the rack, can be pulled out easily.



(*a*) (*b*)

FIG. 43

92. After the entire run has been laid up in temporary fashion, it is permanently lashed by first *banding*, or wrapping the entire mass of cables at frequent intervals with stout, waxed linen twine. For small horizontal runs these bands may be 5 feet apart, and for large vertical runs they may be as close together as 6 inches. The number of wraps in each band depends also on the size and position of the run, varying from two or three, as a minimum, to about fifteen, as a maximum. Only one such band is shown in Fig. 43 (*b*). After banding, the cable run is stitched through both horizontally and vertically, the stitches dividing the cable run into equal divisions. As shown in view (*a*), the vertical stitches are made four cables apart and the horizontal stitches five cables apart.

The needle used in sewing consists of a long, fairly flexible steel strap of sufficient length to reach through the cable run in its longest direction. This has a hook or eye at one end and it is so formed as to present no sharp edges which might in any way injure the cable. This needle is best worked by two men, one on each side of the run, except in cases of small runs. One man shoves the needle through between the cables close to a band; the man on the opposite side pulls it through, drawing the attached waxed linen cord through after it, and

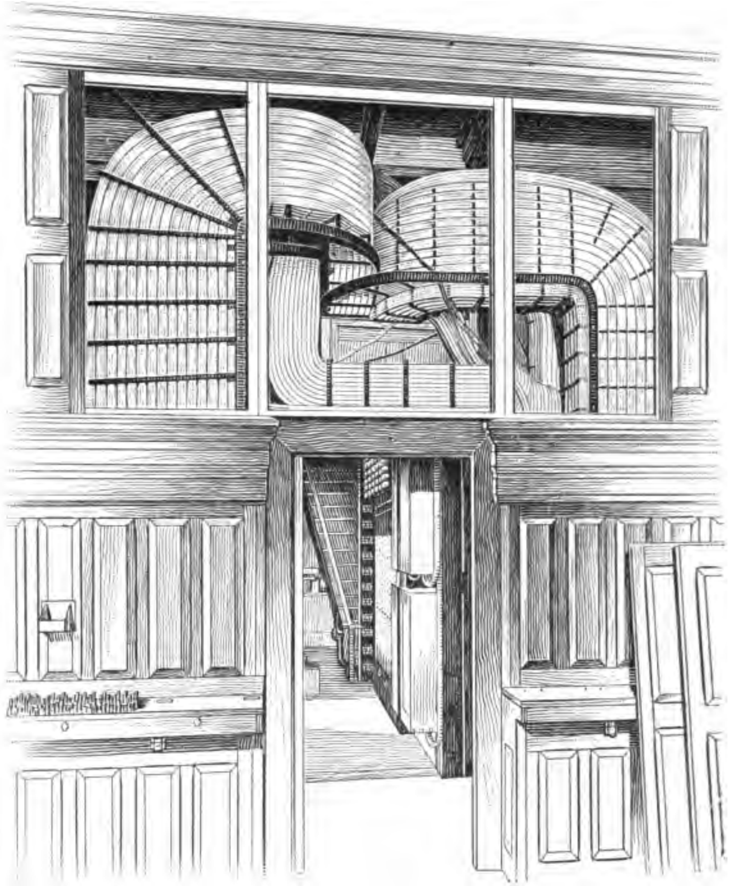


FIG. 44

shoves the needle back between the same cables but on the other side of the band. After passing the twine back and forth through the cable run, first on one side and then on the other side of a band a number of times, depending on the size and position of the run, the stitches are drawn tight so as to pull the binding on opposite sides of the run toward each other.

At each binding in the cable run illustrated in Fig. 43 are three sets of vertical stitching at intervals of four cables and three sets of horizontal stitching at intervals of five cables. The vertical stitches enclose a crosspiece of the runway. The entire cable run is thus bound firmly together and to the rack. Fig. 44 shows the neatness and security with which large curved cable runs may be stitched and supported. After the permanent lashing is completed, the temporary stitches used while laying the cable are cut and pulled out.

93. Safeguards against damage by fire and water are important features of all telephone cable work. Long vertical shafts or cableways form excellent chimneys, and they should therefore be closed at floor lines to restrict or prevent drafts. The shafts should be of fireproof construction and should be kept free of all refuse and debris that constitute a fire hazard.

ARRANGEMENT OF APPARATUS IN A LARGE SWITCHBOARD

94. Every one engaged in switchboard work should become thoroughly familiar with the names and locations of all the cables in the boards with which he is concerned. The arrangement is not the same in all boards, but a large multiple board such as shown in Fig. 45 is typical, and if understood, other boards will not prove difficult to understand.

The rear of one section of the board is here shown with the curtain raised to reveal the interior. This curtain is similar to those employed in roll-top desks, and when raised rolls up in the curtain shield shown at the top. Hanging down from the top may be seen a pull strap attached to the edge of a tarpaulin, two of which are placed on each switchboard section ready to be pulled down over both the back and the front in case of fire, principally to prevent damage by water.

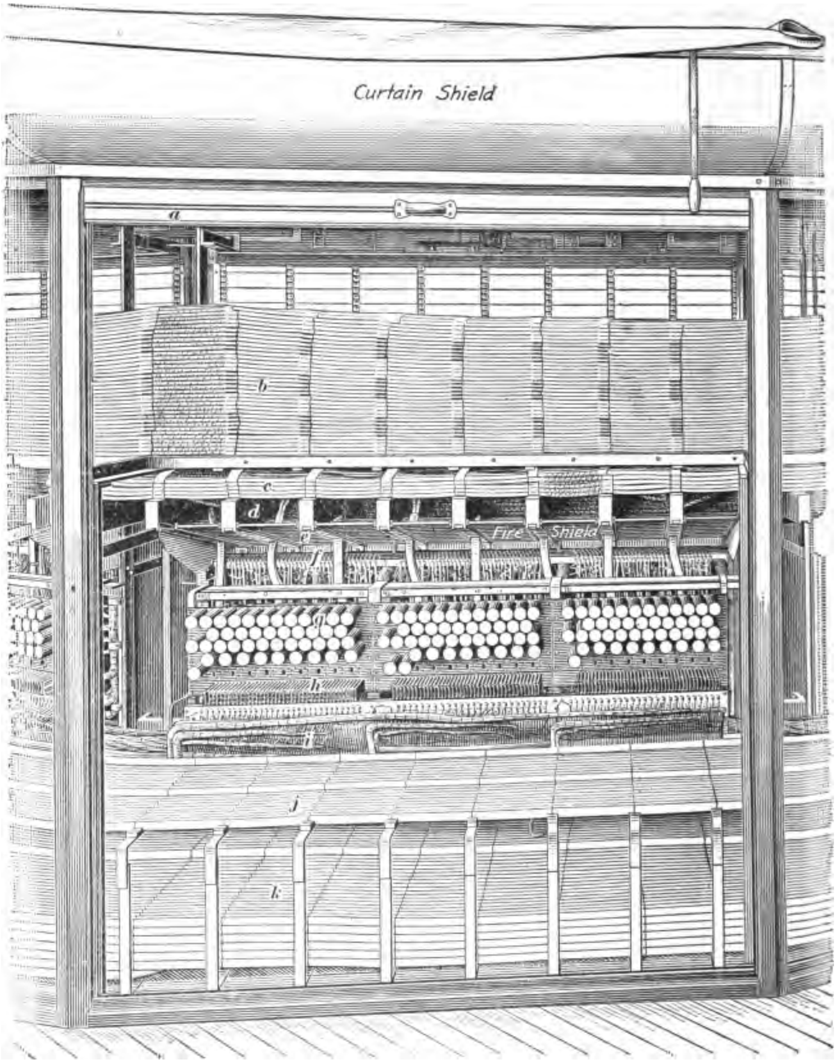


FIG. 45

95. In the roof of the board, partly concealed by the curtain rail, is the wiring and apparatus *a* of the operator's telephone sets. Immediately below this is the subscribers' multiple cable run *b*, or the subscribers' multiple, as it is called. This is the cable that is fanned out at every section to reach all of the subscribers' multiple jacks. Below the subscribers' multiple cable is the outgoing trunk multiple *c*; this is the multiple cable that reaches to the outgoing trunk jacks on the switchboard below the subscribers' multiple jacks. Below the trunk multiples are the cable forms *d* of the answering jacks and lamps, which occupy the lowest space of all on the vertical face of the board.

Just under the answering jack cable forms is an inclined partition *e* of fireproof material, called the fire-shield. This is for the purpose of protecting, so far as possible, the answering jack forms and the subscribers' and outgoing trunk multiples from fires that may originate in the apparatus and circuits below. Overheating is most likely to occur in the apparatus located lower down in the switchboard.

96. Immediately below the fire-shield, Fig. 45, is the cord terminal rack *f* on which all of the flexible cords are terminated. Below these may be seen the cord circuit relays *g*—that is, the supervisory and other relays—each of which is enclosed within its own tubular shell. Just below these are the cord-circuit resistances *h*, employed in connection with the supervisory lamps.

The terminal rack and the cable forms at *i* below the cord resistances are for the cables leading to the cord-circuit repeating coils, which are necessarily mounted outside the switchboard. The large cable run at *j* contains the repeating-coil cables, and on the lowermost runway at *k* are the answering-jack cables. These repeating-coil and answering-jack cable runs gradually diminish in size as the cables are led off from them to each successive position.

97. In Fig. 46 are shown several methods of stowing away the tarpaulins, used for fire and water protection, on the top of the board. This is an important item, and one with which the switchboard workman should thoroughly familiarize himself before the actual necessity for its use arises. When this necessity does arise, the work must be done hurriedly. The chief operator or supervisor should also be instructed in the operation of the tarpaulin.

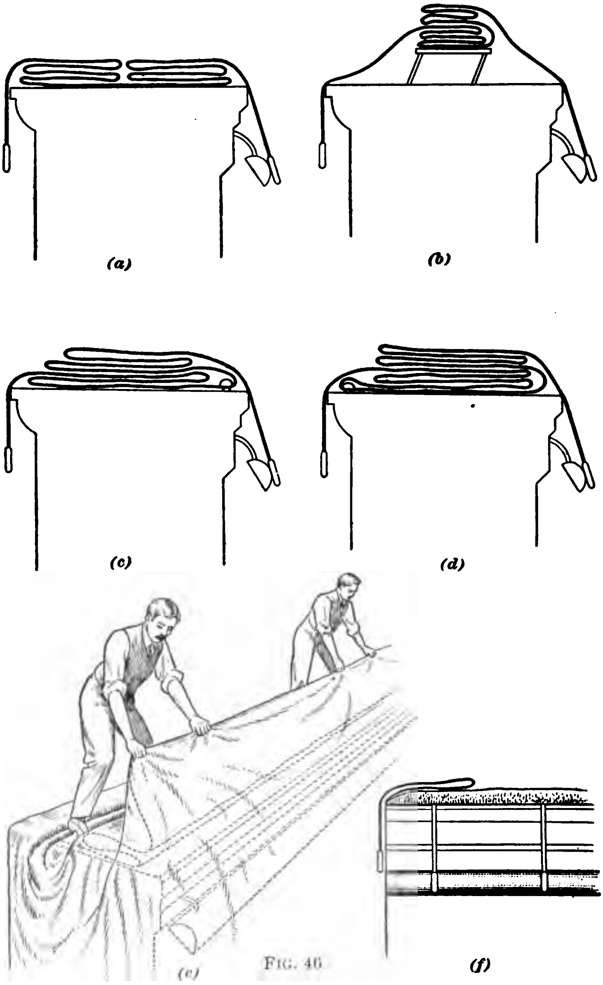


FIG. 46

POWER PLANT

GENERAL STATEMENTS

98. The central-office power plant is the assembly of apparatus required to furnish the several kinds of current used in the operation of the telephone plant. The electrical energy is commonly purchased from the local power company and converted in the central office into the form of energy needed for telephone purposes. In some cases a suitable generator driven by a gas engine or other prime mover is used to produce the energy instead of purchasing it; in other cases both methods of supply are made available so that either can be used in case of failure of the other.

99. In general, both direct and alternating currents are required for telephone work. Direct current is used for operating transmitters, relays, line supervisory and auxiliary signals, and for busy tests. So far as the direct current is employed in the talking circuits, it must be absolutely *smooth current;* that is, there must be no sudden pulsations such as might be caused by the commutation of the ordinary direct-current generator used for lighting purposes. For this reason batteries are always used to supply current for talking purposes, storage batteries in large exchanges, and primary batteries (dry cells) where each telephone has its own individual battery. Alternating current is used for ringing ordinary polarized bells, and interrupted, or pulsating, direct current for ringing biased party line bells.

MAGNETO POWER PLANT

100. In a magneto, or local-battery, system the ringing current is supplied by magneto generators and the talking current by local batteries, and these devices are distributed all over the system. In such a system the power plant is generally understood to be only the generating apparatus in the central office for the use of the operators when signaling and talking to subscribers.

101. The current for operators' transmitters in small magneto offices is usually furnished by primary batteries, a separate battery being used for each transmitter. In large magneto offices, however, a low-voltage storage battery may be used, all of the different operators' transmitter circuits being fed in multiple from this battery. The low internal resistance of a storage battery permits its use as a common source of current supply for a group of operators' transmitters, without introducing cross-talk, provided individual transmitter leads are run to the terminals of the battery or very heavy common leads are provided from the battery to the point where the individual circuits branch off.

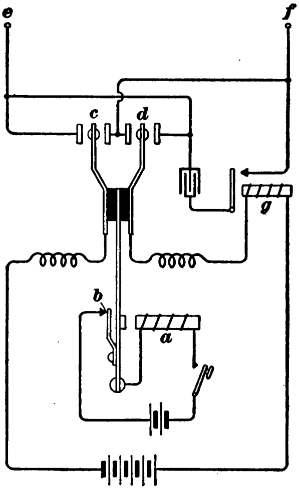


Fig. 47

102. In very small magneto offices the ringing current is supplied by a hand generator, the crank of which is mounted on the front of the switchboard. If the exchange is at all busy, however, a device called a *pole changer* is frequently employed to change battery current into alternating current. The theory of the Warner pole changer, which is much used, will be understood by referring to Fig. 47. A magnet *a*, excited by current from a small battery, causes a vibrating arm to break and make contacts at *b*, *c*, and *d*. Contact *b* serves to keep the arm vibrating by opening and closing the circuit of relay *a*. Contacts *c* and *d* serve to complete circuits from a larger battery through the terminals *e* and *f* so that the direction of current in a circuit connected with these terminals will be in alternately opposite directions. The arm vibrates continuously as long as the circuit of relay *a* is closed, but electricity flows from the larger battery only when a circuit is completed between the terminals *d* and *e* by closing a ringing key (not shown). During this flow a relay *g* closes the circuit of a condenser that bridges contacts *c* and *d* and so protects them by absorbing the energy that would otherwise cause sparking at the contacts. When all the ringing keys are open the condenser circuit is open, and no electricity flows from the larger battery.

COMMON-BATTERY POWER PLANTS

STORAGE BATTERIES

103. The most important element of a common-battery power plant is the storage battery. In its simplest form a storage cell consists of two lead plates immersed in an electrolyte consisting of a dilute sulphuric-acid solution, and several such cells constitute a battery. When these plates are connected with a source of electromotive force in a way to set up direct current through the solution between the plates, chemical changes occur in the cell. Such a current is called *charging current* and the process is called *charging the cell.*

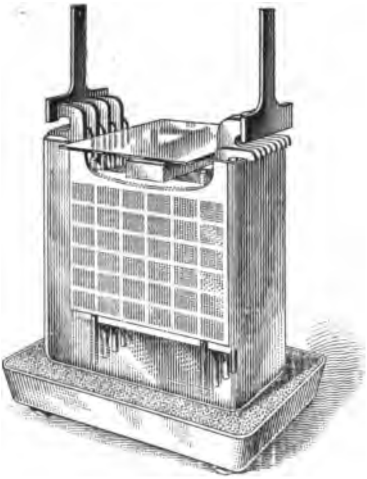


FIG. 48

After the cell has been charging for some time and is disconnected from its charging source, it is capable of causing a *discharge current* in a circuit formed between its terminals. The direction of the discharge current through the cell will be the reverse of the direction of the charging current. Thus, the cell, when charged, acts the same as a primary battery.

The storage cell employed in telephony usually consists of a number of parallel plates, the chief constituent of which is lead.

These plates are held in a containing vessel, which is usually a rectangular glass jar for the smaller size of cells, and a lead-lined wooden tank for the larger sizes. A glass-jar cell is shown in Fig. 48, and a larger lead-lined tank in Fig. 49.

104. The voltage of a storage cell varies according to the state of charge of the cell. During the charge, when the state of complete charge is approaching, the voltage may be slightly higher than 2.5 volts. When the cell is nearly discharged it may be as low as 1.7 volts.

The storage batteries employed for furnishing talking current in common-battery offices usually consist of eleven cells connected in series. Such a battery is commonly referred to as a 24-volt battery, although its voltage may be considerably higher or lower than this, according to the state of charge. The interior of a large central-office storage-battery room is shown in Fig. 50. A large 24-volt battery appears in the foreground with space in the cells for additional plates when more current is required. The small batteries in the rear are for miscellaneous purposes.

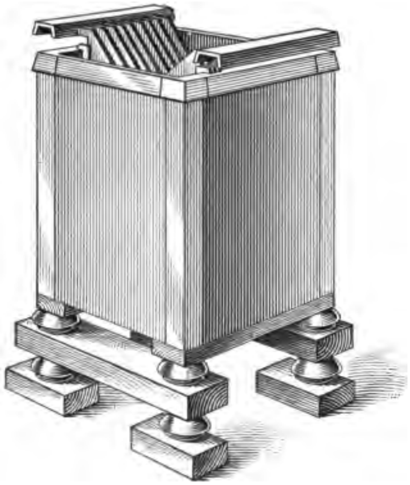


FIG. 49

105. Care, Charging, and Maintenance of Storage Batteries.—Proper care of the storage battery is one of the most important duties connected with central-station operation. The service of the entire system depends on the condition of the storage battery, which may be ruined by improper care. One of the principal points in handling a storage battery is to make sure that the charging current is always applied in the proper direction; that is, with the positive pole of the charging

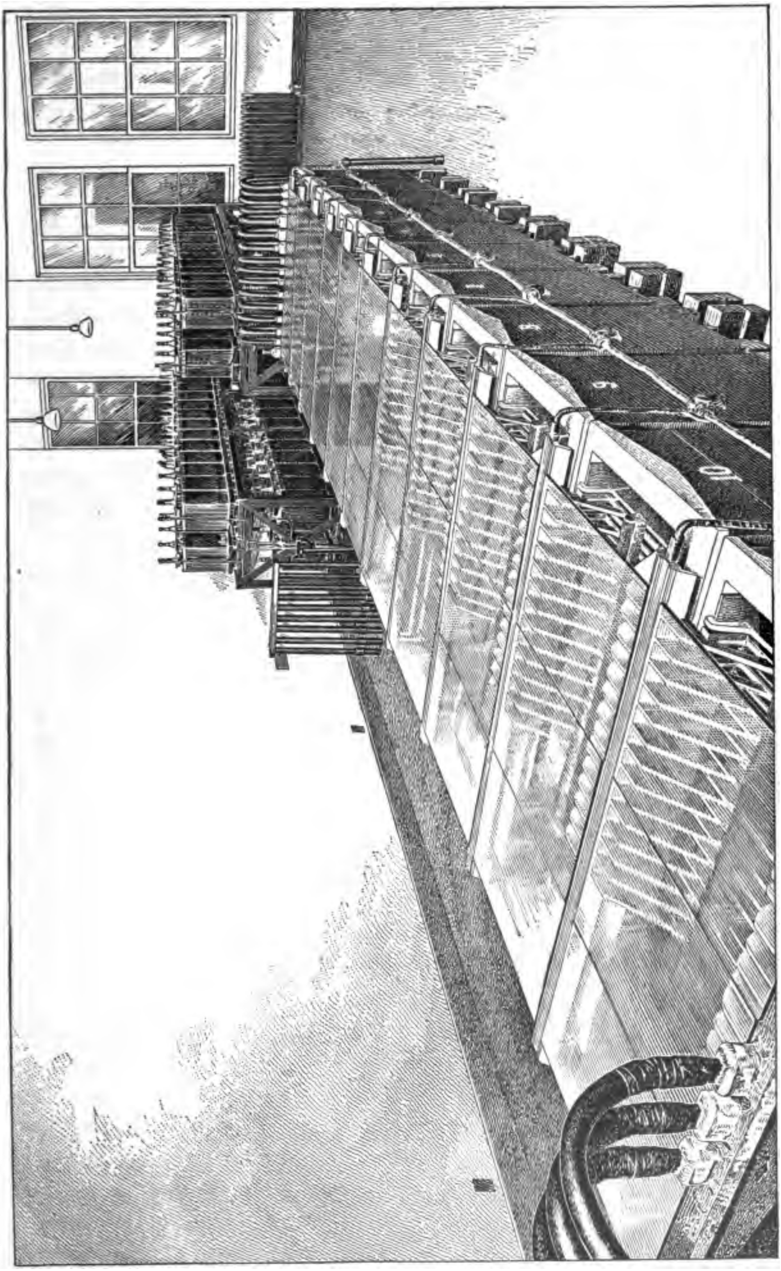


FIG. 50

source connected to the positive pole of the battery. A charging current in the reverse direction would quickly ruin the battery.

106. The following instructions are given for the installation, charging, and maintenance of storage batteries: If the glass-jar cell is used, the cells are placed in trays partly filled with sand so as to prevent the leakage of current that might otherwise be caused by the collection of moisture on the outside of the jars. If wooden tanks are used, they are mounted on glass or porcelain insulators, and sufficient clearance is provided between the adjacent cells to prevent short circuits by contact of the lead linings. The positive and negative plates are welded to bus-bars in such manner that the positive plates of one cell will be connected to the negative plates of the next in the series.

107. The next step is to fill the cells with electrolyte and give the initial charge. A solution of sulphuric acid having a specific gravity of 1.18 to 1.19 is poured into all the cells simultaneously, as nearly as possible; that is, a small amount is poured into each cell in rapid succession, continuing until all are full rather than to fill one cell completely before starting the next. By specific gravity is meant the relative weight of the electrolyte compared with the weight of an equal volume of water. In general, adding sulphuric acid increases the specific gravity. The greatest care should be taken that the water and acid are pure, and in mixing them *the acid should be poured very slowly into the water; never pour the water into the acid*, or violent chemical reaction will occur as evidenced by much sputtering and heat.

108. As soon as every cell contains a little of the electrolyte, the charging should be begun, slowly at first and increasing gradually as the cells are being filled until the full charging rate is reached when the cells are full. During the initial charge, the amperes, the volts across each cell, the specific gravity, and the temperature of the electrolyte should be recorded hourly. The voltage and the specific gravity will gradually rise to a maximum during the charge, and the charge should be continued for 10 hours after the maximum point is reached. During this time the cells will *gas* freely—that is, the electrolyte will apparently boil, and gas will be given off. The battery room must be well ventilated, especially during the initial charge of large cells, otherwise the temperature may increase to such an extent as to cause undue evaporation of the electrolyte.

109. The battery must be recharged at regular intervals. The operation of recharging also necessitates care to avoid both overcharging and undercharging. Repeated overcharges decreases the life and capacity of the cell, and undercharging, on the other hand, results in *sulphating* of the plates, with their consequent disintegration. Sulphating usually makes itself apparent by white spots on the plates.

To minimize the chances of repeated overcharging or undercharging of the battery, it is charged regularly to slightly under its rated capacity, and at longer intervals an overcharge is made. All cells then receive their proper charge, and the sulphating that may have occurred in undercharged cells is reduced. The frequency of making the regular charges depends on the size of the cells and the amount of energy taken from them. Their condition should be observed periodically by testing both the voltage and the density of the electrolyte. The voltage test is easily made and it furnishes a very rough indication; the density test of the electrolyte is much more reliable. The voltage should not be allowed to drop below 1.8 per cell, nor the specific gravity of the electrolyte below 1.19 before recharging. If the regular charge is found necessary once a day, the overcharge should be given, perhaps, once a week.

110. The positive plates should be a chocolate-brown color and the negative plates a clear light-gray or lead color. Their color indicates their condition; they should be watched carefully and attended to promptly if the color changes. If the voltage of one cell drops faster than that of the others or its electrolyte has lower specific gravity, or if it gases less during charge or overcharge, the cell is in poor condition. The cause may be a collection of sediment in the bottom of the containing vessel. If this sediment has risen to within ½ inch or less of the plates, it should be removed by means of wooden or glass scoops shaped so that they can be worked down beside the plate next the wall of the vessel. If it is necessary to remove a plate, it should be immersed in dilute sulphuric acid until replaced in the electrolyte. The best time to clean the tank is just before overcharging.

111. Sources of Charging Current.—Storage batteries can be charged by means of direct-current generators in the central office or the energy may be obtained from the local lighting company. If the energy is received from the lighting company in the form of alternating current, it can be transformed to direct current for charging by means of mercury-arc rectifiers. Generators used for charging such batteries are provided with an unusually large number of commutator bars in order to obtain a very smooth current. The charging voltage must be susceptible of regulation between limits wide enough to keep it slightly above the battery voltage during the charge. This regulation is usually obtained by means of a rheostat, or adjustable resistance, in the circuit of the generator field. This rheostat serves to adjust the strength of the magnetic field and thus adjusts the voltage.

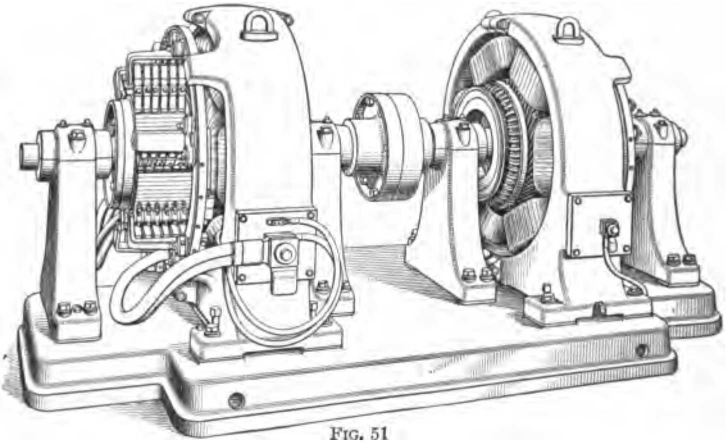


FIG. 51

112. The generator may be driven by a gas engine or an electric motor. The most common practice is to use a motor-generator, that is, two machines with a single shaft or with coupled shafts. Either an alternating-current motor or a direct-current motor may be used. A motor starter is necessary, except for very small motor-generators, to keep the starting current within safe limits. This starter consists essentially of an adjustable resistance or a rheostat for direct-current motors, and either a rheostat or a voltage-transforming device for an alternating-current motor. In any case the starting current is limited by the resistance or the reduced voltage, and the resistance is gradually cut out or the voltage is increased as the motor speed increases. A common form of motor-generator, consisting of a 30-volt generator direct coupled to a direct-current motor, is shown in Fig. 51.

113. Mercury-arc rectifiers are used for charging batteries in small and medium-sized exchanges where only alternating current supply is available. The essential part of such a device is a glass tube, or bulb, Fig. 52, from which the air has been exhausted, the vessel containing a small amount of mercury. Three metallic terminals and a small starting terminal serve for making connections between the outside and the inside of the tube, and the device has the peculiar property of allowing electricity to flow between these terminals only in one way, acting practically as an open circuit when electricity starts to flow in the other direction. These tubes, when connected into the circuit with suitable transformers, will change alternating current to direct current of suitable voltage for charging storage batteries. The perishable part of mercury-arc rectifiers is the glass vessel, which must be replaced after comparatively long intervals of use, owing to its gradual change. One or more tubes should be kept on hand.

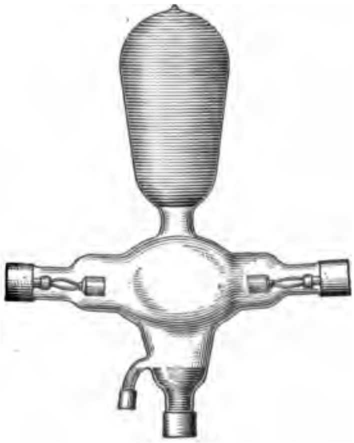


FIG. 52

114. In very small exchanges, storage batteries are sometimes charged directly from lighting circuits by connecting a bank of ordinary commercial incandescent lamps in the charging lead, the number and arrangement of lamps being so proportioned as to give the required charging current. Especial care must be taken not to connect the storage battery directly across a circuit with voltage considerably higher than that of the battery, as this would result in a disastrous current. The direct method of charging cannot, of course, be employed except where direct current is available, and in any event it is a wasteful method.

RINGING MACHINES

115. When the demand for ringing current is beyond the capacity of hand generators, the current may be obtained from electric batteries and pole changers or from ringing machines, the latter being common in large exchanges. One of these machines is shown in Fig. 53 and an installation of ringing machines and other motor-generators for special signaling purposes is shown in Fig. 54. The driving motors of all the

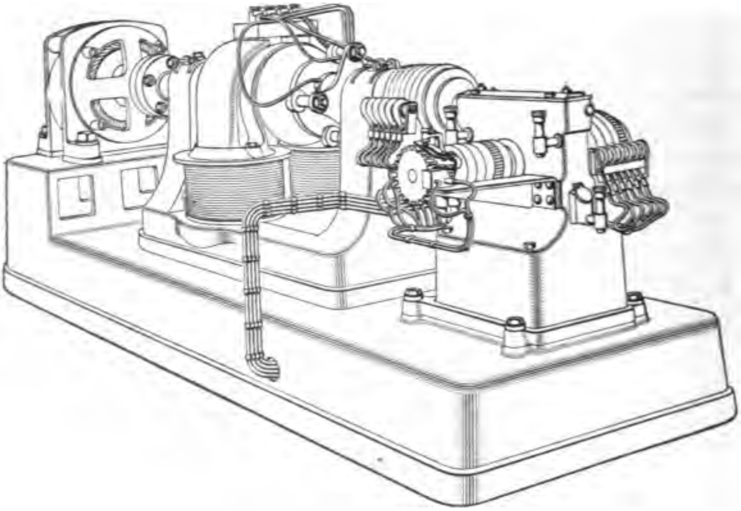


FIG. 53

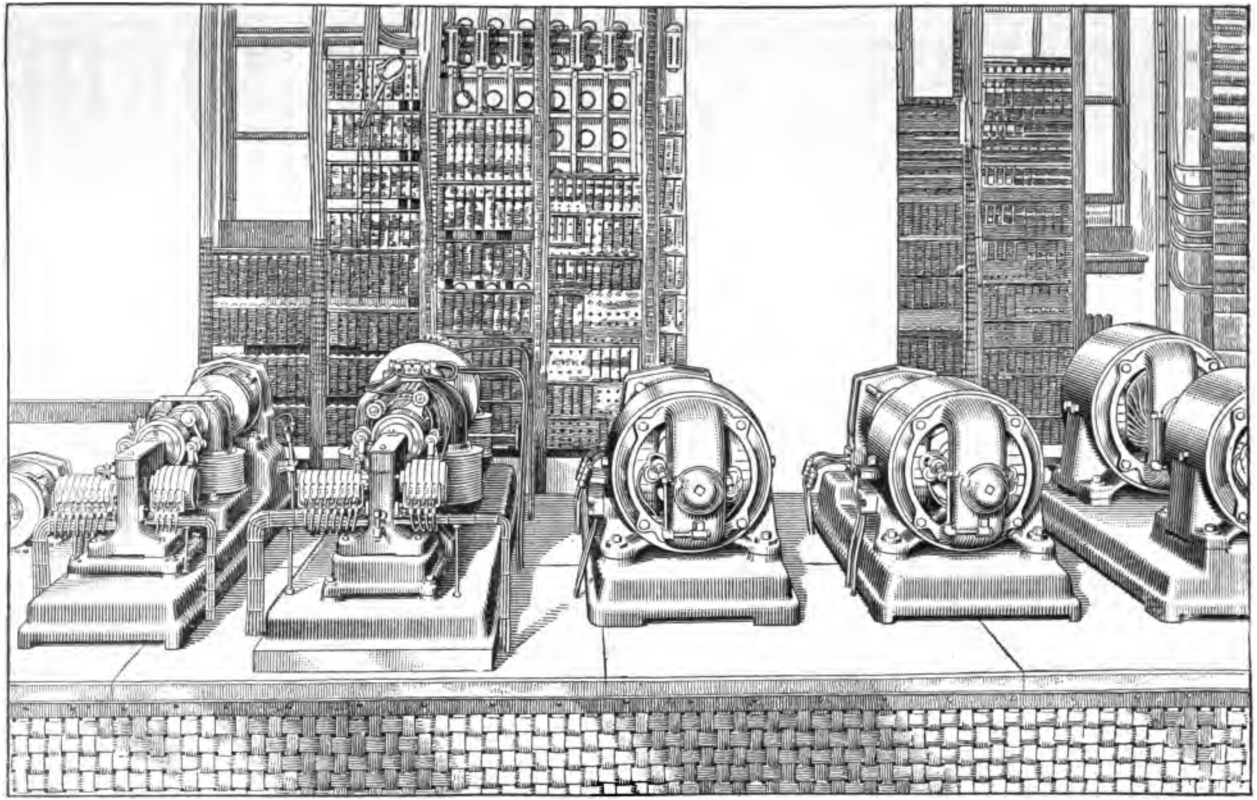


Fig. 54

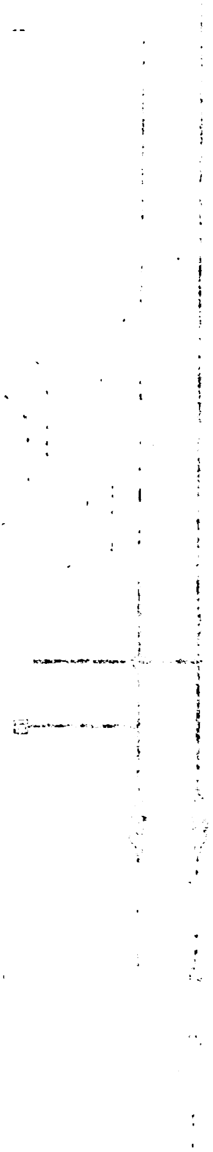
motor-generators may receive energy from an outside source or from the storage battery. Frequently, duplicate sets are provided, one arranged to operate from each source, so as to insure continuity of service.

116. Care of Charging and Ringing Machines.—The chief requirements in the care of charging and ringing machines are to see that the bearings are well lubricated, the commutators and slip rings or sliding contacts clean, and all stationary contacts secure. Hot bearings can be detected by the sense of feeling, the bearing being safe as long as the hand can be held on the housing comfortably. If a bearing becomes too hot, look at once to see that its oil ring is turning properly and that the lubricant is reaching the bearing surface.

POWER SWITCHBOARD

117. The power switchboard consists of panels, usually of slate or marble, on which are mounted the various switches for controlling the motor and generator circuits, the starters for the motors, the rheostats for regulating the generators, the protective devices for the various power circuits, and the meters for measuring voltages and currents.

118. The protective devices on a power switchboard in a telephone office consist of fuses and circuit-breakers. The fuses are merely strips of metal forming parts of the circuit, these strips being so proportioned that they melt and open the circuit when the current becomes too large for safety. A circuit-breaker is a switch that is closed against the action of a spring and held by a magnetically operated latch. If the current becomes too large, it causes the magnet to release the latch, allowing the circuit-breaker to snap open. The release magnet can also be arranged so that a reversal of the current or a failure of voltage will cause the breaker to open. When the unusual conditions that cause a fuse to blow or a circuit-breaker to open are removed, the circuit can be again closed either by putting in a new fuse or simply closing the circuit-breaker.



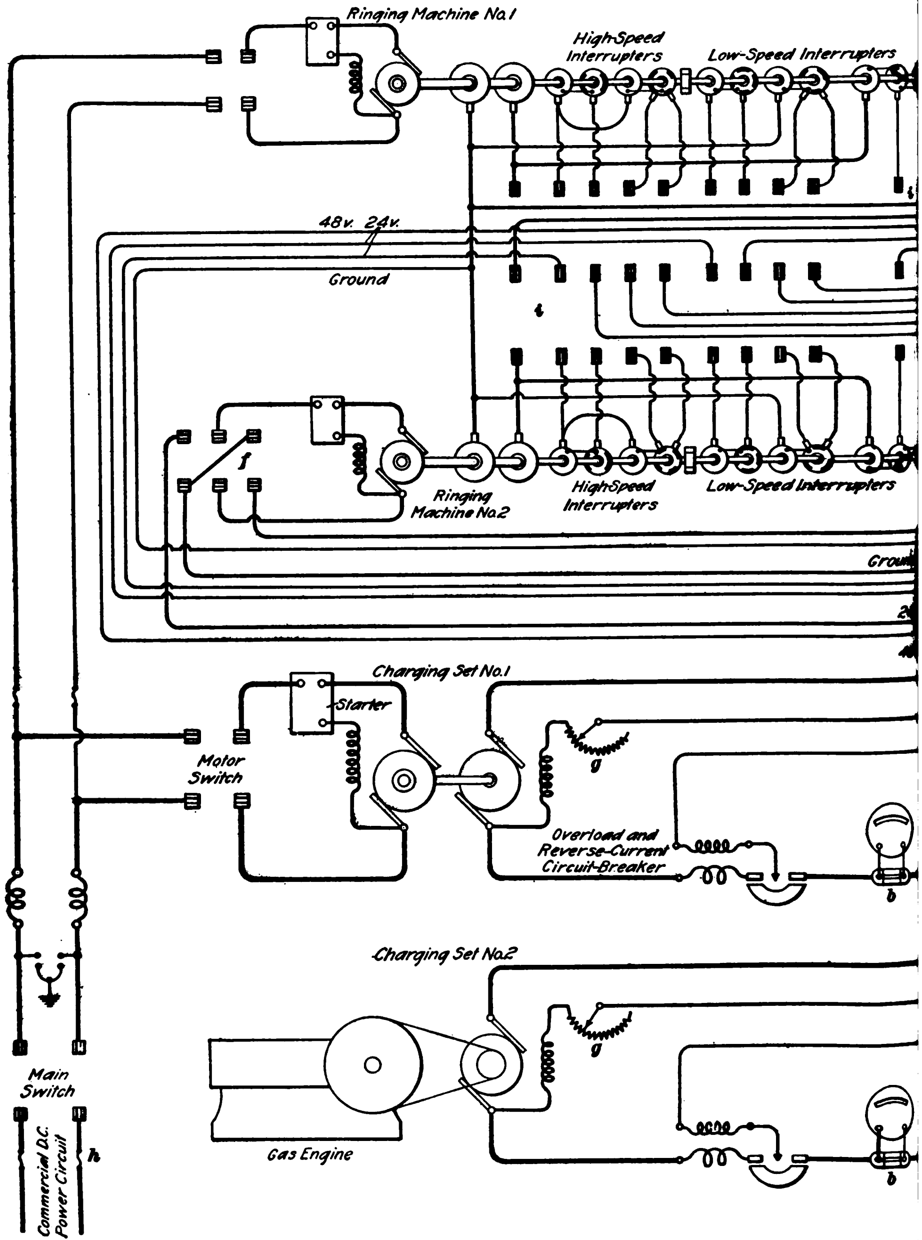
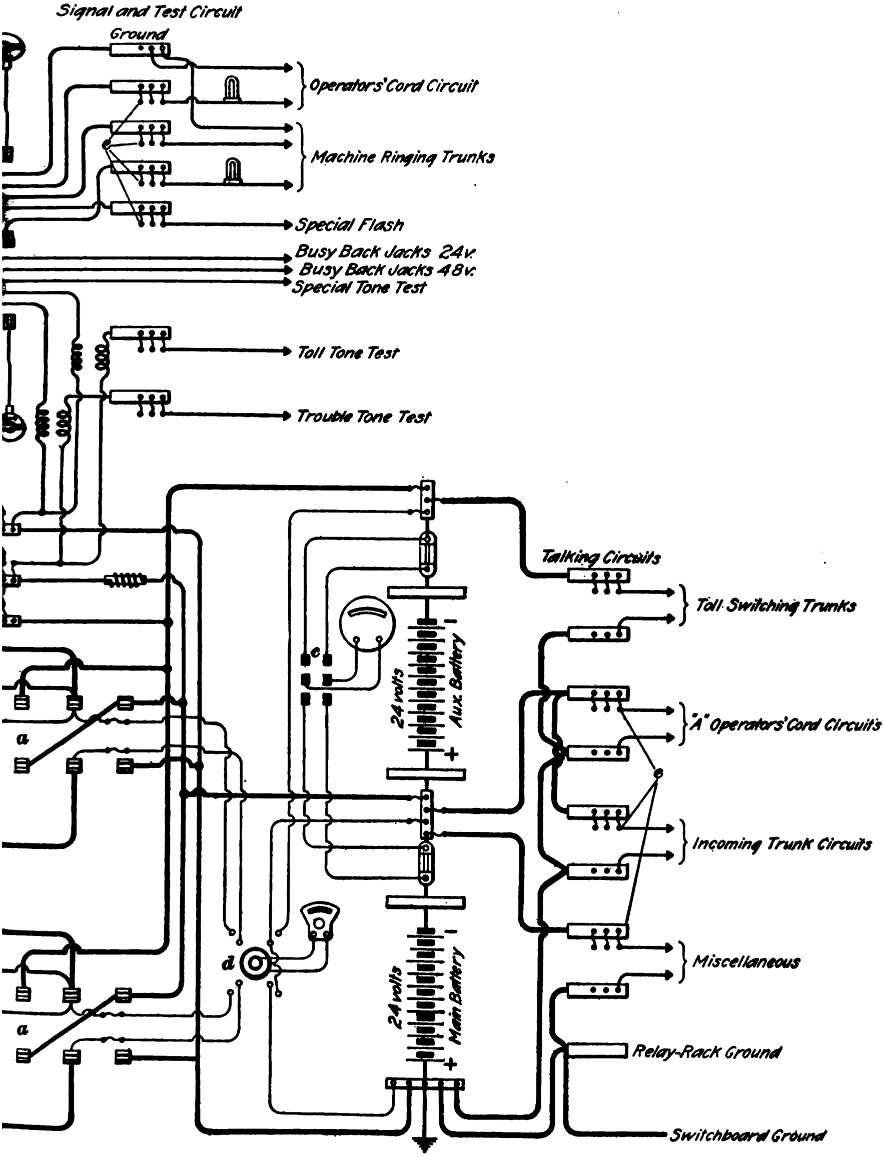

Ringing Machine No. 1
High-Speed Interrupters
Low-Speed Interrupters
48 v.
24 v.
Ground
i
f
Ringing Machine No. 2
High-Speed Interrupters
Low-Speed Interrupters
Charging Set No. 1
Starter
Motor Switch
g
Overload and Reverse-Current Circuit-Breaker
b
Charging Set No. 2
g
Gas Engine
b
Main Switch
Commercial D.C. Power Circuit
h

FIG.


Signal and Test Circuit
Ground
Operators' Cord Circuit
Machine Ringing Trunks
Special Flash
Busy Back Jacks 24v.
Busy Back Jacks 48v.
Special Tone Test
Toll Tone Test
Trouble Tone Test
Talking Circuits
Toll Switching Trunks
"A" Operators' Cord Circuits
Incoming Trunk Circuits
Miscellaneous
Relay-Rack Ground
Switchboard Ground
24 volts
Aux. Battery
24 volts
Main Battery
e
d
a
a
+
-
+
-

119. Fig. 55 shows the circuits of a common-battery power switchboard, this arrangement being in use in some of the large Bell offices. One of two charging sets receives energy from the commercial power system and the other is driven by a gas engine. Two batteries are employed, a main battery of 11 cells and a smaller auxiliary battery of 11 cells. Either battery alone gives 24 volts average, and the two in series give approximately 48 volts for the toll switching trunks. Either generator can be connected with either battery by means of a double-pole double-throw charging switch *a*.

In each generator circuit is an overload and reverse-current circuit-breaker and an ammeter shunt *b*. A similar shunt is connected in series with each battery. The voltage drop in each of these shunts is proportional to the current, and the ammeters connected with them are calibrated to indicate the entire current. By means of a double-throw switch *c* one ammeter can be made to indicate the current in either battery circuit. A switch *d* serves to connect a voltmeter so as to indicate the voltage of either generator or either battery.

Fuses *e* in the talking circuits and in the signal and test circuits afford protection from injury by foreign currents. Two ringing machines are employed, No. 1 receiving energy from the power circuit and No. 2 from either battery, according to which way the double-throw switch *f* is thrown.

120. In each central office are usually provided full instructions for operating the power plant. These instructions should be carefully followed by the operator. Before starting a charging set, see that the charging switch is open; the set should be brought up to full speed, the circuit breaker closed, and the voltage adjusted by means of the field rheostat *g* until the generator voltage is about half a volt higher than the voltage of the battery with which the generator is to be connected. Then note the discharge current from the battery about to be charged, close the charging switch, and increase the generator voltage by means of the field rheostat until the generator ammeter shows the proper charging rate plus the discharge current. Care must be taken, however, not to overload the generator.

121. In shutting down a charging set, the generator current is first reduced to a few amperes by adjusting the field rheostat, after which the charging switch, the circuit-breaker, and the motor switch are opened in the order named. If the motor starter is automatic, the handle will return to the off-position without further attention; otherwise the operator should move the starter handle to its off-position as soon as the motor has stopped.

122. Spare fuses should be kept available, especially those for the main power circuit, as indicated at *h*, since the blowing of these fuses stops the entire power supply and necessitates starting the emergency charging set No. 2 as well as the emergency ringing machine No. 2. Double-throw switches *i* enable the signal and test circuits to be connected with either ringing machine.

OUTSIDE PLANT

SURFACE PLANT

GENERAL FEATURES OF OUTSIDE PLANTS

1. The **outside plant** of a telephone exchange is the system of circuits necessary to interconnect subscribers' stations and the central office. The outside plant may be considered as consisting of two parts, the *surface plant* and the *underground plant*. As an independent circuit must be provided between the office and each station, for at least every group of four stations, the number of circuits is very much larger than is necessary for light and power service in the same territory.

2. When the subscribers are few and widely scattered, the outside plant may consist chiefly of bare wires carried on poles—the original form of outside lines. But this form of construction is too expensive, both to install and to maintain, for practicable service in large communities. Exposed aerial conductors are liable to damage by storms and to contact with branches of trees and with other wires; as the number of circuits increases, the difficulties increase. Aerial and underground cables afford more reliable means of communication in larger communities and are less expensive to maintain.

3. Fig. 1 shows in one view the different types of circuits that may be employed in the outside plant of a telephone exchange. The protector in a subscriber's residence is joined by means of a twisted pair, called the *subscriber's drop wire*,

COPYRIGHTED BY INTERNATIONAL TEXTBOOK COMPANY. ALL RIGHTS RESERVED

with a pair of bare copper or iron wires ending at insulators on the cross-arm of a near-by pole. These bare wires, called the *aerial*, or *open*, *wires*, extend to a protector equipment in a *cable terminal* on a pole, perhaps a few hundred yards and possibly several miles away, in the outskirts of town. The circuit then continues toward the central office enclosed in a lead-covered, paper-insulated *aerial cable*, containing wires for twenty-five or more other subscribers. The protector equipment guards the aerial cable and the central-office apparatus from the injury to which they are liable on account of the exposed open wires. If the subscriber is located in a thickly settled part of the town, the drop wire is connected directly to the aerial cable terminal without the intervening span of aerial wire. In this event the protector equipment would be omitted and a smaller and more compact terminal substituted.

As the central office is approached, the aerial cable increases in size, usually twenty-five or fifty pair being added at a time to meet the additional requirements of subscribers picked up en route, until further increases are prohibited by weight and other limiting factors. The aerial cable then terminates in an *underground cable box* containing protector equipment, from which the circuit to the central office is enclosed in an *underground cable*. The underground cable is enclosed in a *subway* composed of two or more ducts, each approximately 3 inches square in cross-section. At intervals of from 300 to 500 feet along the subway, *manholes* provide means of access to the subway for placing, removing, or repairing cables.

The underground cable extending through the subway to the central office is made up of paper-insulated conductors. In the cellar of the central office this cable is spliced into smaller cables, usually made up of 100 pair each, and these smaller cables are extended through a shaft or runway to the main frame in the terminal room.

DROP WIRING

4. **Drop wire,** Fig. 2, usually consists of a twisted pair of No. 16 or 18 Brown & Sharpe gauge copper wires each insulated with a weather-proof covering; No. 17 copper-clad steel wire is also much used. If snow and sleet storms are likely to cause unusual stresses, No. 14 Brown & Sharpe gauge copper wire or No. 14 Birmingham gauge iron wire, well insulated in either case, is used. Drop-wire insulation generally consists of an inner layer of rubber and an outer layer of cotton braid saturated with a weather-proof compound.

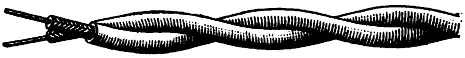


FIG. 2

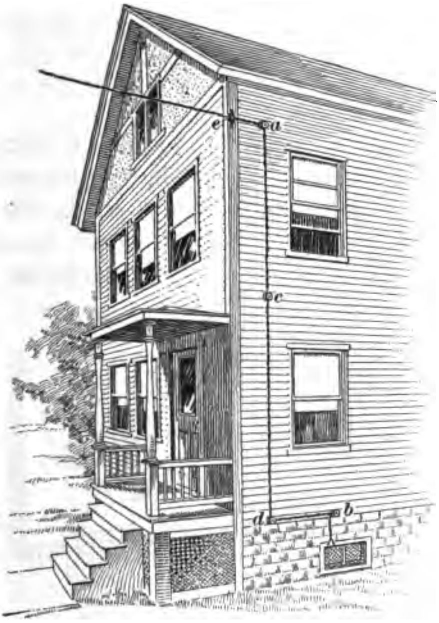


FIG. 3

5. When about to install a drop wire, the installer should make a survey of the premises, taking into consideration the relative location of the poles with respect to the building and the interference of obstacles, such as trees, between the pole line and the subscriber's residence. If possible, the drop wire should be brought in from the street or court at the side or back of the house. If adjoining property must be crossed, the drop wire should be run in an inconspicuous place where it will not interfere with the operation of clothes-lines nor present an unsightly appearance from windows.

Having determined the most desirable run from the pole line to the building, the installer should place the coil of drop wire on the ground at the foot of the pole in a position so that the wire will feed from the inside of the coil. The end of the wire should be pulled to the top of the pole, drawn over the cross-arm or the bracket, and pulled back to the ground. The drop should then be pulled directly to the subscriber's premises by the installer, while his helper pays out the wire from the inside of the coil. When the house is reached, the drop wire should be drawn over

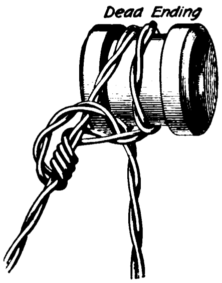


FIG. 4

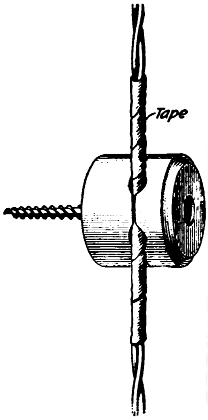


FIG. 5

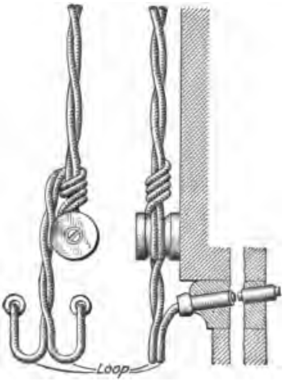


FIG. 6

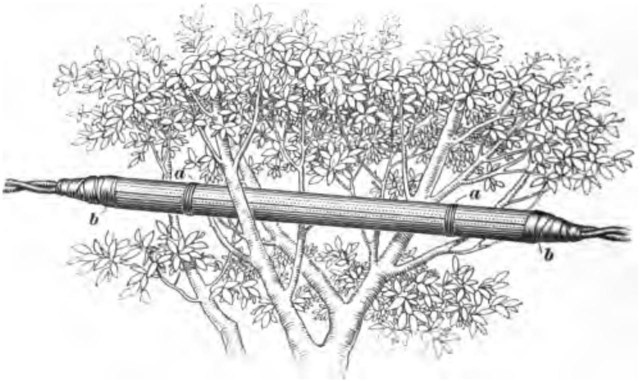


FIG. 7

a knob placed high enough on the house to keep the wire clear of all obstructions, as at *a* in Fig. 3, until enough slack is obtained to reach the protector block located inside of the cellar window. The drop should be *dead ended*, as shown in Fig. 4, at knobs *a* and *b*, Fig. 3, the porcelain insulator having a groove around which the wire is wrapped. Insulators with removable caps, as shown in Fig. 5, can be used to clamp the wire and guide it in horizontal and vertical lines on the side of the building, as at *c* and *d*, Fig. 3. An insulating guide ring should be attached to the corner of the house, as at *e*, if there is likelihood of the drop wire chafing against the corner.

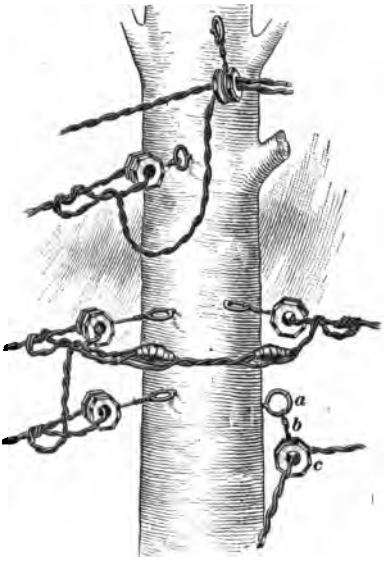


FIG. 8

By one method, Fig. 6, the drop wires enter the building through two holes provided with insulating bushings, which slant downwards from within. By a later method, both wires enter through one hole. A slight loop should be given the drop wire at the point of entrance, to drain off the moisture. In some cases the dead-end insulator is placed below the entrance hole, thus eliminating the necessity of the drip loop.

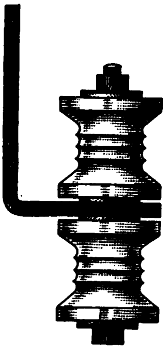


FIG. 9

6. The next step is to pull slack from the drop wire, starting at the house and working toward the pole and making the attachments to the knobs secure. Unless special conditions require greater elevation, the drop wire should be 25 feet over railroad crossings, 20 feet over highways, 15 feet over sidewalks, and 12 feet over private property.

If trees are unavoidable in running the drop wire from the pole to the house, the wires should be temporarily drawn over the tree branches, and permanent attachment made later, at the time the slack is removed from the line. In some cases mechanical protection to the drop wire may be necessary, and a split wooden tubing can be used, as shown in Fig. 7. The two parts of the tube are fastened together by copper wire *a* and adhesive tape *b*. Drop wire so protected cannot be injured by the moving branches. Attachments to trees are sometimes necessary and can be made, as shown in Fig. 8, by means of screw eyes *a*, galvanized-iron wire *b*, and porcelain insulators *c*.

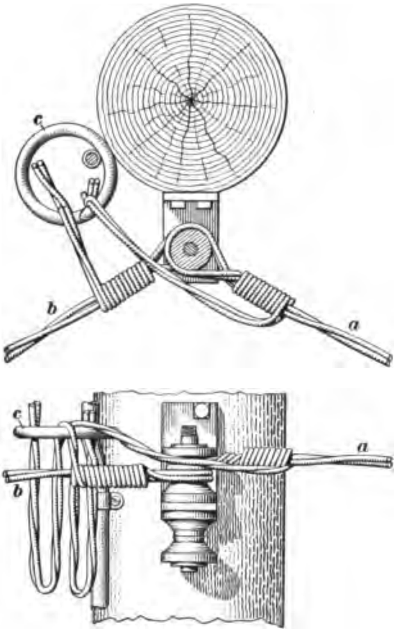


Fig. 10

7. For attaching a drop wire to a pole carrying a terminal box, a bracket such as shown in Fig. 9 is used. The bracket is attached to the pole and the drops dead ended on the knobs as shown by two views in Fig. 10. Two drops can be dead ended on one insulator, as at *a* and *b*. The free ends are then looped down through a ring *c* before they enter the box. The pull of the wire thus exerts no stress on the terminals. The ring serves to keep all the loops in a compact mass:

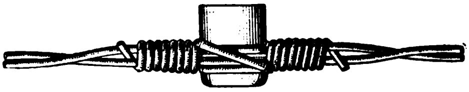


Fig. 11

If two or three poles intervene before the terminal box is reached, the drop wire may be dead ended at an insulator on the nearest pole and then carried from pole to pole, being fastened, as shown in Fig. 11, to an insulator on each intervening pole until the pole carrying the terminal is reached. Here it is again dead ended as in Fig. 10.

Fig. 12 shows methods of arranging the pole terminals of the drop wire, view (*a*) indicating the manner of dead ending the drop and (*b*) the manner of carrying it past a wire and connecting it with two other aerial wires beyond.

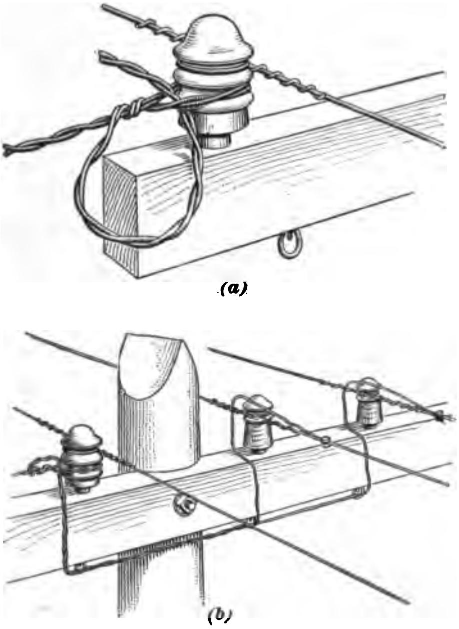


FIG. 12

BLOCK WIRING

8. In commercial and high-class residential districts, the drop wires are gathered in groups called **block, or bridle, wires,** and carried in inconspicuous places along buildings, back fences, or short poles erected near the property lines in the rear of dwellings or business places, to conveniently placed terminals. The bridle wires are fastened in place by means of open rings, Fig. 13, which

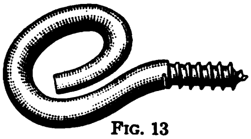


FIG. 13

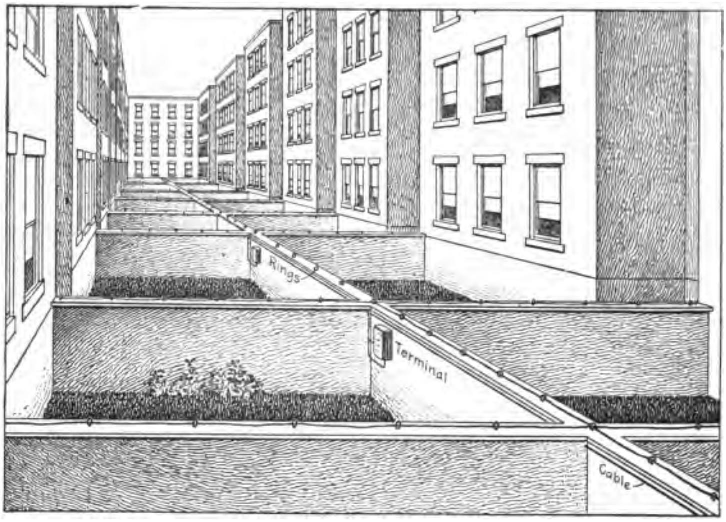


FIG. 14

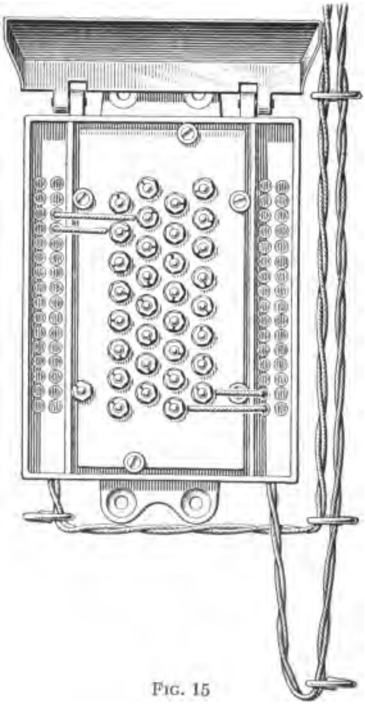
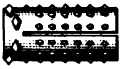


FIG. 15

permit the addition or removal of drops. Fig. 14 shows the relative location of cables, terminals, and rings for block wires on fences, and Fig. 15 shows the method of making connections inside a terminal box.



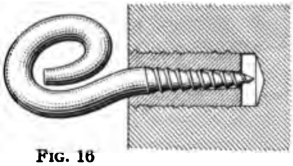


FIG. 16

9. On brick walls the bridle rings are screwed into **expansion shields** as indicated in Fig. 16. This shield is a malleable-iron casting with an irregular outer surface and a taper-threaded hole inside. It is placed in a hole drilled near the center of the exposed face of a brick and when the ring is screwed into place the shield expands against the walls of the hole and is securely held. In horizontal runs, a ring should be placed in every sixth brick.

POLE LINES

TELEPHONE POLES

10. The poles best adapted for telephone work are Michigan cedar and second-growth chestnut. Poles should be cut from growing timber, when the sap is down; they should be reasonably straight and free as possible from knots and rot. After the bark has been removed and the knots trimmed, notches, known as *gains*, Fig. 17, are cut in the side of the pole, near the top, for the cross-arms, and the tops of the poles are made wedge shaped, called *roofing* them. The object of the roofing is to drain off moisture, which might otherwise collect and rot the top of the pole.

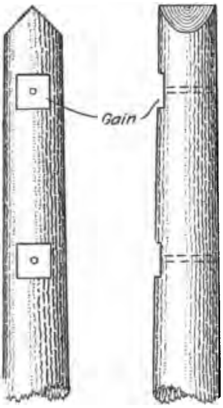


FIG. 17

Replacing poles in a pole line is an expensive operation, and to reduce such expenses many companies use means of preserving the useful life of poles. These means may consist simply of painting the roof, the ga~~ins, and~~ the surface of the pole near the ground level with a wood preservative. In some cases the butts of the poles up to a point somewhat above the ground line, or even whole poles, thoroughly dried, are immersed in a tank of creosote long enough to allow the preservative to penetrate some distance into the wood. A protecting band of concrete is sometimes built around the pole after it is erected, the band extending for a short distance below and above the ground level, which is the place where decay usually begins.

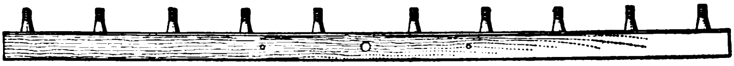


FIG. 18

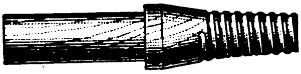


FIG. 19

The surface of the pole immediately underneath the bark is toughest and best able to withstand weather conditions; hence, this surface should be scarred as little as possible when removing the bark and the knots.

11. Fig. 18 shows the outline of a 10-foot, ten-pin cross-arm, the arm most commonly used in telephone lines, and Fig. 19 shows the form of pin generally used. The pin is driven into a hole in the cross-arm, and held by a nail. An insulator is then screwed onto the threaded part, as indicated in Fig. 20.

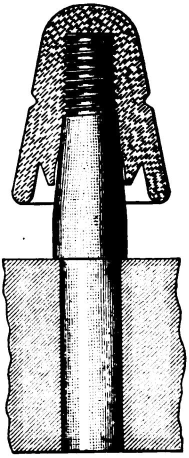


FIG. 20

The arm fits into a gain in the pole and is held by a *through bolt*, Fig. 21, and two *braces*, Fig. 22, the assembly being as shown in Fig. 23. The braces are fastened to the cross-arm by *carriage bolts*, Fig. 24, and to the pole by a *lagscrew*, Fig. 25, of suitable size.

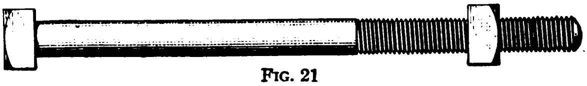


FIG. 21

The poles used in town and city work are sometimes *stepped*, especially where climbing is often necessary; Fig. 26 shows a

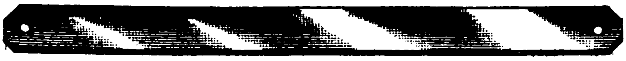


Fig. 22

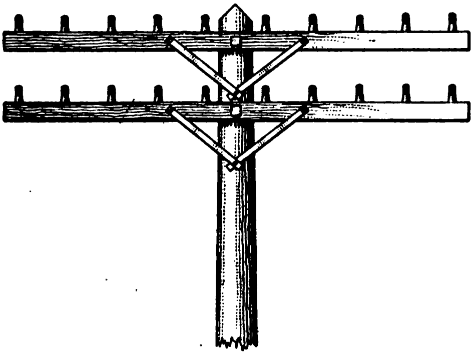


Fig. 23

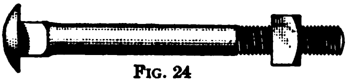


Fig. 24

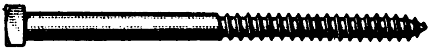


Fig. 25

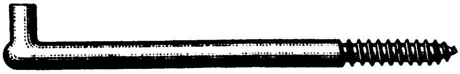


Fig. 26

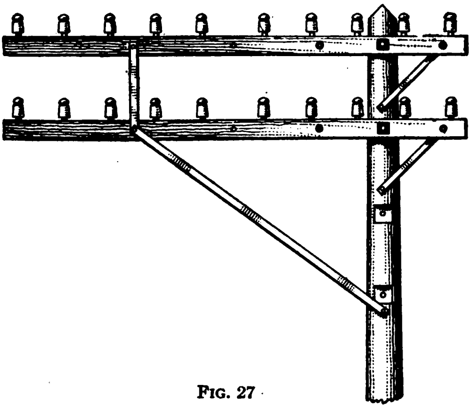


Fig. 27

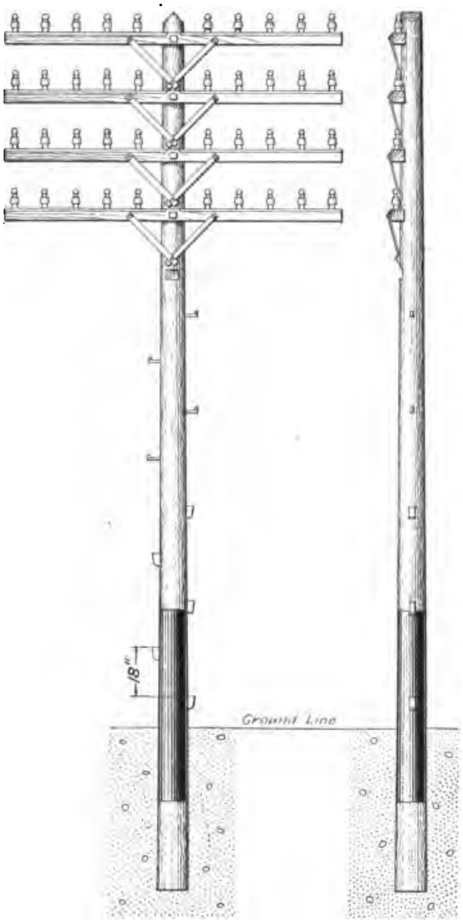


FIG. 28

standard form of *pole step*. The step is driven into a hole bored in the pole to a depth of 2 or 3 inches for cedar and 4 inches for harder wood. The outer edge of the step should be approximately 5½ inches from the pole. In order to reduce the danger of injury to pedestrians and vehicles, the lower five steps are made of triangular pieces of wood nailed to the poles. The steps are equally spaced, alternate steps being on opposite sides of the pole, and the distance from each step to the level of the step next above or below it is usually 36 inches. Fig. 27 shows a variation of the usual method of mounting cross-arms for use in alleys or near buildings where the space is limited on one side of the pole, and Fig. 28 shows a pole completely equipped and stepped.

POLE HARDWARE

12. The cross-arm braces, through bolts, carriage bolts, lagscrews, and pole steps are usually referred to as the *pole hardware*. The hardware used should be made of either wrought iron or mild steel and should be capable of standing a 90-degree bend, with a radius equal to the thickness of the stock, without injuring the steel on the outside of the bend. The breaking strength of bolts and lagscrews should be as follows: 3,400 pounds for $\frac{3}{8}$-inch diameter, 6,300 pounds for $\frac{1}{2}$-inch diameter, and 10,000 pounds for $\frac{5}{8}$-inch diameter.

All pole hardware, including the nuts and the threads on the bolts, should be thoroughly galvanized to prevent rusting. To test the galvanizing, pole hardware should be capable of withstanding four consecutive 1-minute immersions in a saturated solution of sulphate of copper without exposing the surface of the iron under the galvanizing.

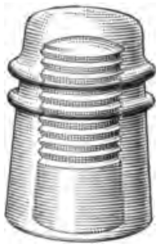


Fig. 29

Insulator glasses are usually of a form shown in Fig. 29. Before placing the insulators on the pins they should be carefully inspected for flaws. This precaution may save considerable time and money that would otherwise be expended in replacing defective insulators.

PLACING POLES

13. As a rule, holes should be from 4 to 8 feet deep, depending on the height of the pole and the character of the soil. Fig. 30 shows the tools generally used for digging telephone pole holes, namely, a post-hole shovel *a*, a spoon shovel *b*, a digging bar *c*, and a post-hole auger *d*. The holes should be started with a marking stake placed in the center, and should be of sufficient diameter to allow the pole to slip easily into place without carrying with it a quantity of dirt. In general, holes should be from 4 to 6 inches larger than the diameter of the base of the pole. When the soil is frozen or consists of hardpan, it is often better to use dynamite to blast the hole than to attempt to use the auger and digging bar. Dynamite should be used only under the direction of an experienced and licensed dynamiter.

14. If possible, the work should be so planned that no holes will be left open during the night. In soil of average consistency each man should be able to dig from six to eight 6-foot holes per day. A gang of six men can work to good advantage with poles up to 35 feet in length; more men are required for heavier poles. Six men should be able to dig about twenty holes in the forenoon and set the poles in them in the afternoon, provided no unusually difficult conditions are met.

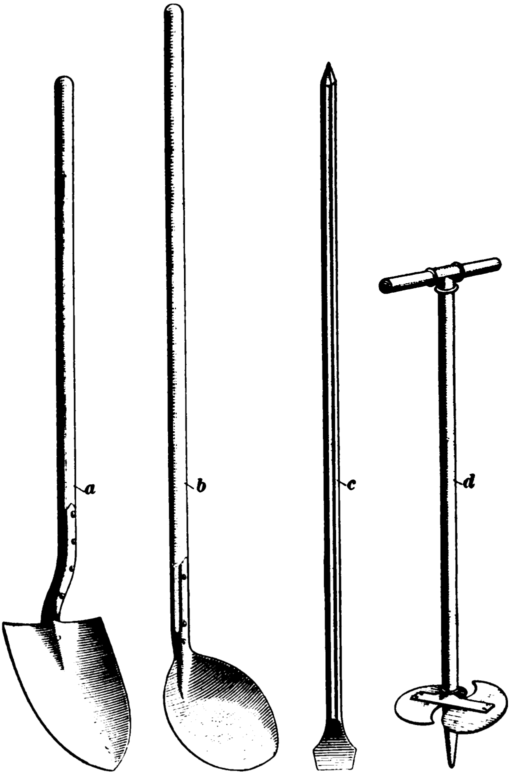


FIG. 30

15. The poles can be set by hand, as shown in Fig. 31, or by the aid of a derrick wagon. For hand setting, six pike poles *a*, Fig. 32, two each 12, 14, and 16 feet long, are required; also two dead men *b*, 6 and 8 feet long, respectively, for supporting the pole in an inclined position as it is raised; one cant hook *c*; two carrying hooks *d*; a piece of oak plank to be used in sliding the pole down into the hole; one set of 4-inch double-sheave block and tackle; about 250 feet of ½-inch rope, and bars for digging and tamping. A short-handle shovel is useful for filling holes. The name dead man is given to any device used to support the pole while raising it. Another form of dead man is shown in Fig. 31.

The pole is rolled or carried to a position where the butt is nearly over the hole and the oak plank is placed against the side of the hole so that the butt will strike it and slide down as the pole is raised. Four men lift the small end of the pole, one man places the dead man under it, and another remains near the hole and rolls or moves the butt with cant hook or crowbar as may be necessary, while he directs the work of the others. As the small end of the pole rises, pike poles are used, and the dead man moved nearer the butt and inclined to prevent slipping, as shown in Fig. 31. The lower end of the pike pole should be placed firmly on the workman's shoulder and held in position by the hands. The upper end should always be inclined toward the hole, and should be about in line with the body of the user

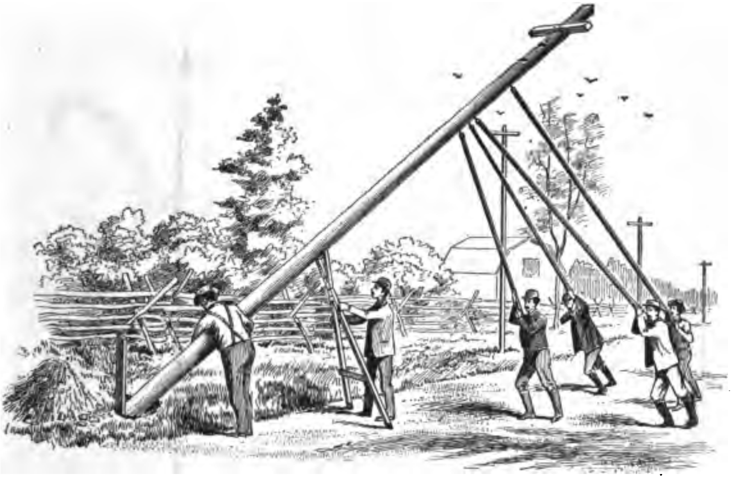


FIG. 31

so as to permit him to push to the greatest advantage. The men should work as nearly under the pole as possible, but should spread out slightly as shown in the figure to prevent the pole from falling sideways. As the pole is raised and while it is supported by the dead man, the men should shift their pikes to a lower position on the pole, one at a time; the longer dead man and successively longer pikes should be used, until the pole is nearly enough erect to slide down into the hole.

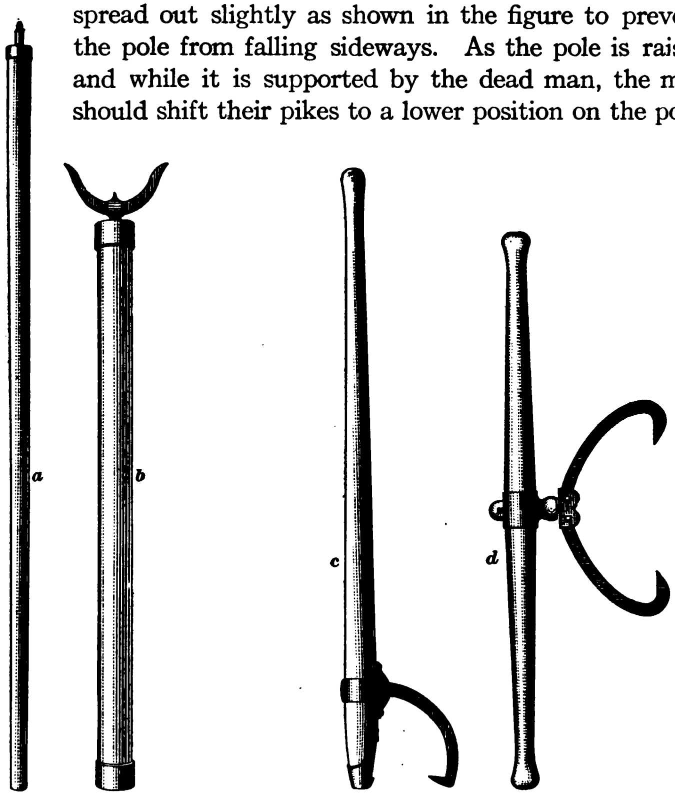


Fig. 32

16. The derrick wagon shown in Fig. 33 usually consists of a heavy truck equipped with a pivoted beam, about 30 feet long, to the end of which is attached a block and tackle. This beam is erected so that the block is nearly over a pole hole, a chain or rope is placed around the pole in a position so that the pole, when raised from the ground, will incline slightly toward the hole, and the pole is raised by a team of horses hitched to the end of the rope engaging the pulleys. Two men guard the butt, tipping it down as the pole is raised, and as soon as it is over the hole, the horses are backed slightly, allowing the pole to sink into place. The pole is then held vertical with pike poles while one man climbs and removes the chain, thus allowing the derrick to be moved and placed in position for setting the next pole. Four men are usually required to operate a derrick wagon, and by its use the number of poles set in a day is considerably greater than the number that six men can set by hand.

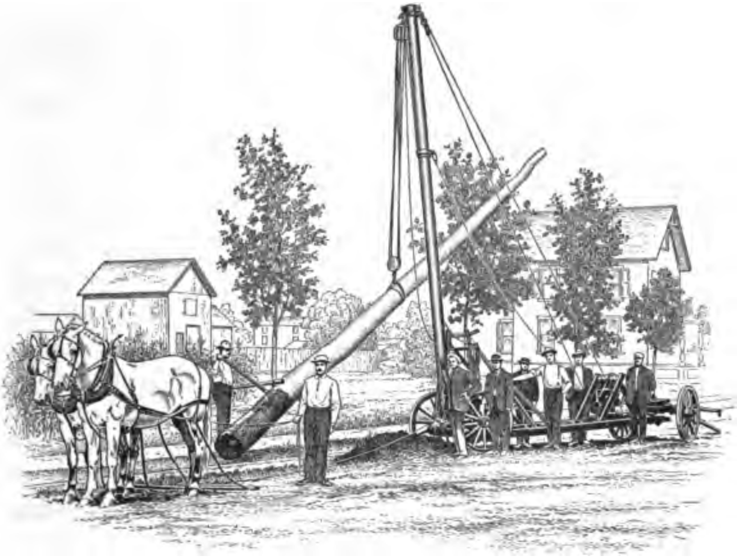


FIG. 33

17. After the pole is brought to a vertical position, it should be turned by means of a cant hook until the gains are properly located to support the cross-arms at right angles to the direction of the line. In so doing it should be remembered that alternate poles are to support cross-arms facing in opposite directions. The remainder of the hole is now filled slowly and the earth thoroughly tamped as it is shoveled in. A heavy tamping bar is used to pack the earth around the pole and a sloping bank of earth is left above the ground surface, as indicated in Fig. 34. If this work is properly done, the poles will remain longer in the position set; otherwise, they are likely soon to sag out of plumb. The men not engaged in filling in and tamping should proceed to the next hole and perform the operations preliminary to raising. An intelligent handling of the men will save much time and expense, and too much attention cannot be given to a proper proportioning of the work.

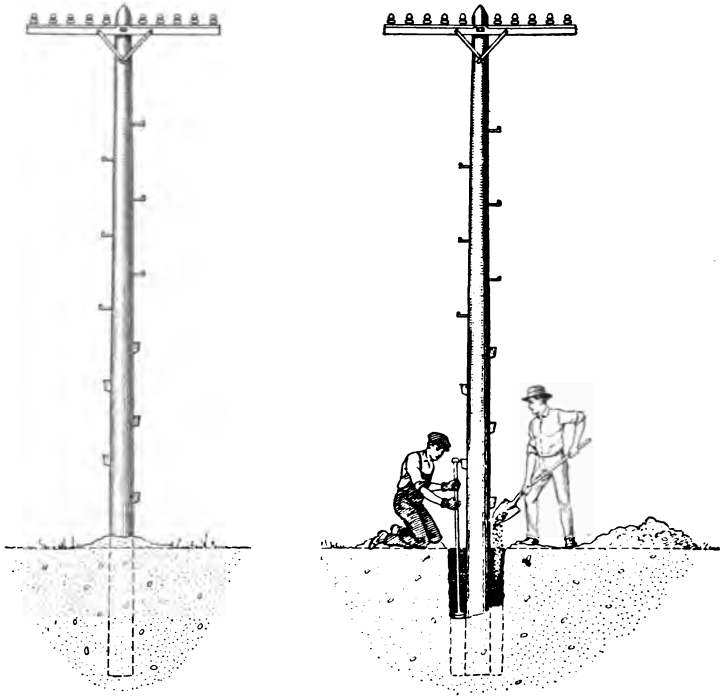


FIG. 34

18. When poles are climbed only at comparatively long intervals, the steps are usually omitted and the climbing accomplished by use of *climbers* of the form shown in Fig. 35. In this climber the rod is strapped to the leg on the same side as the spur. Climbing is a difficult feat and can be attained only by persistent practice. The best way to learn is to practice on the lower part of a pole without attempting an ascent to the top until considerable proficiency has been attained. The main points to be observed are to secure a hold with the spur by a direct downward thrust of the leg instead of with a side thrust toward the pole, to keep the body as far as possible from the pole, and to grasp the pole with the palms of the hands. The descent is more difficult than the ascent, and for this reason a beginner should be cautious about climbing too high at first.

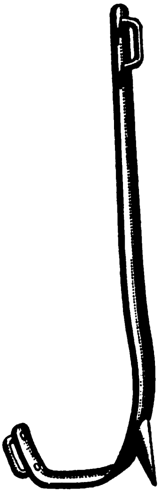


FIG. 35

AERIAL WIRE

19. The two materials used for telephone aerial wire are copper and iron. Copper wire is made by drawing copper stock through successively smaller and smaller holes. Each drawing hardens the wire, and it is softened before the next drawing by a process of heating and cooling known as annealing, which also decreases its tensile strength. If the wire is not annealed after the last few drawings it is known as hard-drawn copper, and its increased tensile strength is useful in supporting both its own weight and the other stresses occurring in spans varying from 100 to 150 feet.

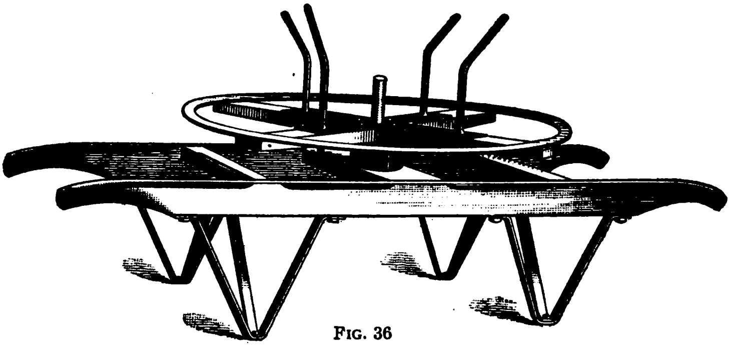
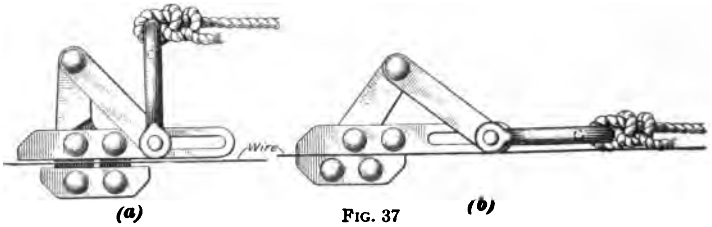


FIG. 36

The conductivity and durability of copper wire is greater than that of iron wire. When these qualities are desired for an aerial line, hard-drawn copper should be used. When a greater strength than that of hard-drawn copper is required, and high conductivity is not essential, iron or steel wire may be used. The corroding, or rusting, of iron wire is a decided detriment to its use in telephone circuits and limits its period of usefulness; galvanizing removes this objection to some extent. An effort to find a wire that would have the qualities both of strength and high conductivity has resulted in the so-called copper-clad steel wire, that is, wire having a core of steel covered by a sheath of copper. Copper-clad steel wire has a conductivity of from 30 to 40 per cent. that of hard-drawn copper; it is considerably softer and is equally well adapted to withstand corrosion.



(a) FIG. 37 (b)

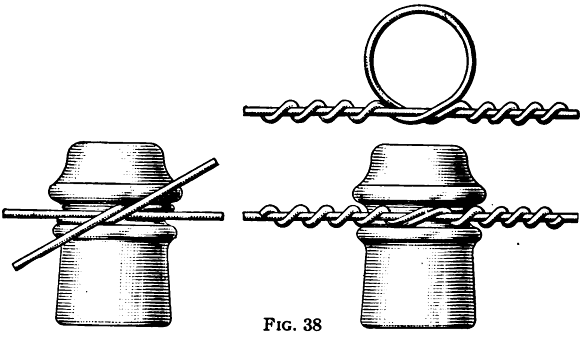


FIG. 38

20. Fig. 36 shows a form of portable reel used for stringing aerial wire. The coil is placed on the reel, which is set in a convenient place, and the end of the wire is gripped in a clamp, one form of which is shown in Fig. 37, view (*a*), with the jaws open, and in view (*b*) with them closed. The rope is pulled over the cross-arm at a point near the pin to which the wire is to be tied, and the reel turns easily on a pivot as the wire is paid out. Fig. 38 shows a method of tying a copper wire to an insulator, and Fig. 39 shows the method generally employed with iron wires. Splices are made the same as with inside wires, except that Western Union joints are not used to splice copper wires. All joints should be soldered.

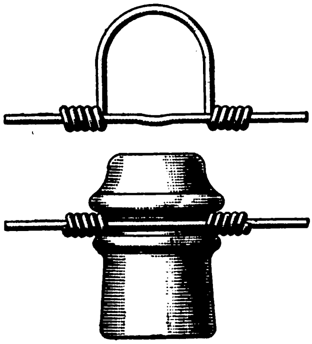


FIG. 39

AERIAL CABLE INSTALLATION

21. Aerial cables are usually advisable where the number of circuits exceeds twenty, and in some cases for a smaller number of circuits. For example, when running through tree tops or close to light and power wires, the circuits can be carried in a cable with less chance of damage or interference than with open wires. Inductive troubles caused in open-wire circuits by current in neighboring light wires can often be entirely overcome by substituting cable for the open wires.

CABLE TERMINALS

22. Protected Terminals.—Aerial cable terminals, or terminal boxes, may be divided into two general classes—*protected* and *unprotected*. Protected terminals are used only where unusual electrical hazards are involved, as in the case of long aerial-wire leads. Figs. 40 and 41 show two types of protected boxes. The equipment of both boxes is essentially the same, consisting of the fuse-carbon type of protector mounted to protect the aerial cable from high potentials and from damaging currents. The protectors in the box shown in Fig. 40 are mounted on one side of the box, as indicated at *a*, and on the other side is placed an ordinary locknut terminal strip *b*. This strip consists of a hard-rubber base on which are mounted small metal posts threaded at the outer end to engage nuts. Short twisted pairs are spliced to the aerial wires on the cross-arm, brought in through the hole *c* in the bottom of the box, and terminated on the strip *b*. The aerial cable enters at *d* and terminates on the strip *a* containing the protectors. The circuits are completed by means of *jumper wires* (short twisted pairs) across the gap *e*.

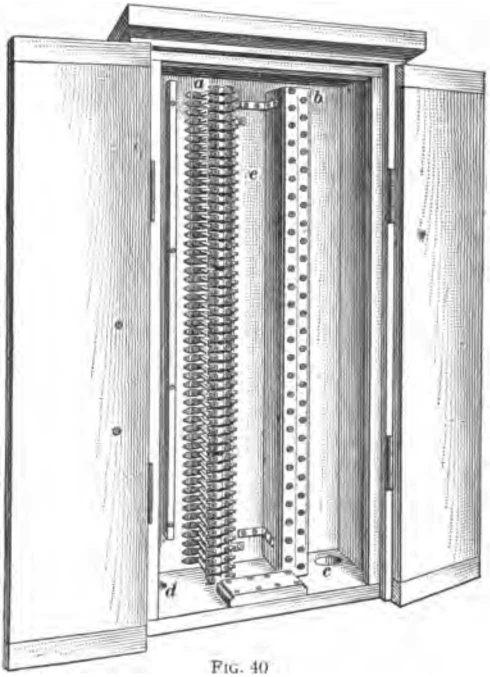


FIG. 40

The form of terminal shown in Fig. 41 consists of two parallel strips of protectors *a* and *b* mounted on a hollow boxlike frame *c*. The cable enters the frame through a hole in the cast-iron base *d* and the pairs of wires are run out through holes in the frame to the protector equipment. When making these connections, the lead sheath is removed from the portion of the cable to be enclosed within the frame, and after the cable has been installed and the wires terminated, the space surrounding the wires in the frame is filled with a moisture-proof insulating compound. This operation is usually performed in the shop,

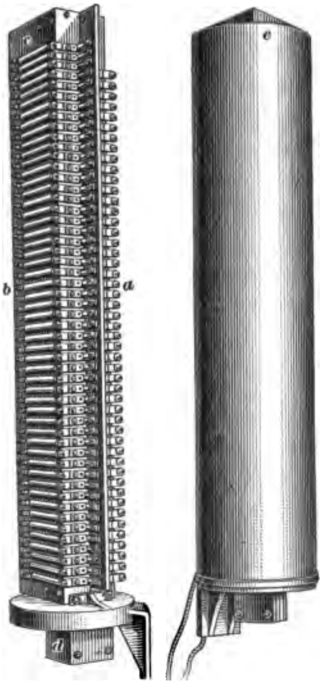


FIG. 41

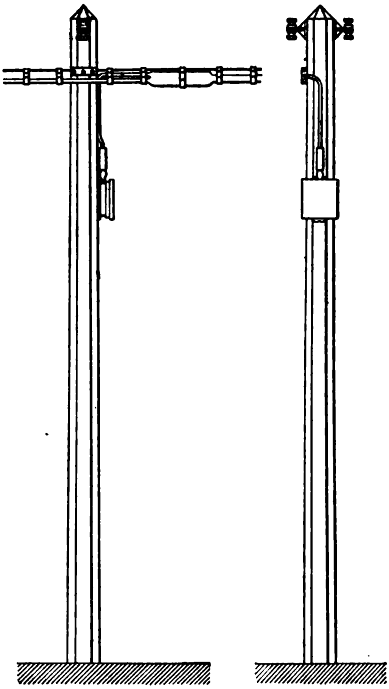
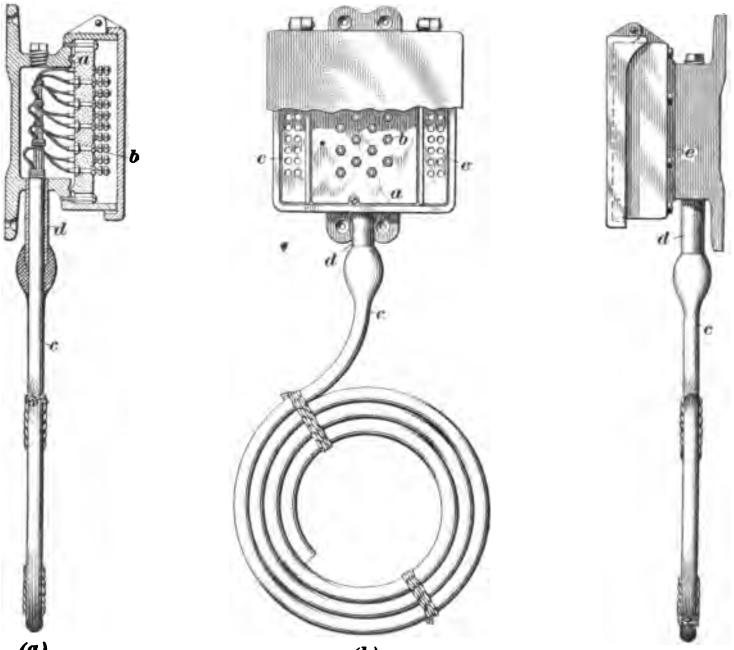


FIG. 42

using a short piece of cable about 6 feet long to which the aerial cable is spliced after the box is installed on the pole. The aerial, or drop, wires are terminated directly on the opposite side of the protector from the aerial cable. A galvanized cover *e* encloses the whole apparatus.

23. Unprotected Terminals.—Fig. 42 shows an unprotected terminal installed on a pole. Three views of the unprotected terminal in most common use are shown in Fig. 43, (*a*) being a sectional side view, (*b*) a front view with part of the hinged cover cut away, and (*c*) a side view of the complete device. The box itself is cast iron, with ridges at the back against which a porcelain slab *a* is mounted. Binding posts *b* in the porcelain slab serve to join the wires of the cable *c* with the drop wires. In manufacturing the box, the sheath is removed from the end of a piece of cable, the wires of which are then soldered to the rear ends of the binding posts, after which the porcelain plate is fastened permanently to the frame. A brass tube *d* just large enough to hold the cable projects through a hole in the bottom of the chamber. The chamber back of the plate is then filled with a moisture-proof insulating compound and the box is ready for installation on the pole and for the splicing of the cable tap *c* to the aerial cable. The object of



(a) (b) (c)

Fig. 43

the moisture-proof compound is to prevent moisture from collecting in the chamber and soaking back into the cable. The drop wires are brought through the holes *e* in the rear of the box each side of the plate and terminated on the outer ends of the posts.

AERIAL CABLE

24. Aerial cable is not depended on for the mechanical strength necessary to support it, but is supported by a strand of steel or wrought-iron cable known as the **messenger strand,** a piece of which is shown in Fig. 44. Before installing aerial cable, the poles on which the stress is to come must be securely guyed, the messenger strand put in place, terminals placed on the poles where needed, and cable rings of the form shown in Fig. 45 fastened on the strand. The cable is then pulled through the rings.

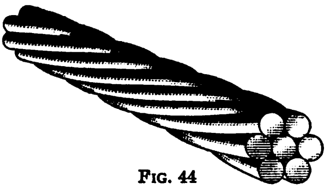


FIG. 44

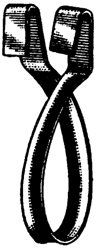


FIG. 45

25. Fig. 46 represents an aerial cable installed on a straight pole line. The pole at one end of the line is **guyed** to an **anchor** and the pole at the other end to a **guy stub.** No stress in the direction of the line comes on the other poles. The anchor is usually a log buried deep in the earth crosswise of the direction of the line with a wrought-iron rod running to the surface, as shown in Fig. 47, and covered with stones and soil packed hard. Another form of anchor, known as the *everstick,* is shown in Fig. 48; this anchor is placed in a hole bored or dug for the purpose and anchor plates are expanded, as at *a*, by striking an expanding bar *b*

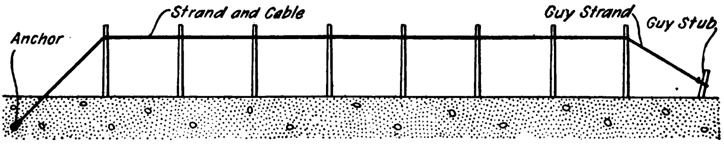


FIG. 46

until it is driven downwards the required distance, after which the hole is filled and the earth firmly tamped as it is replaced. A guy stub is merely a short pole set deep in the earth, usually with a slope, or *rake*, opposite the direction of the stress that will be applied to it, as indicated in Figs. 46 and 49.

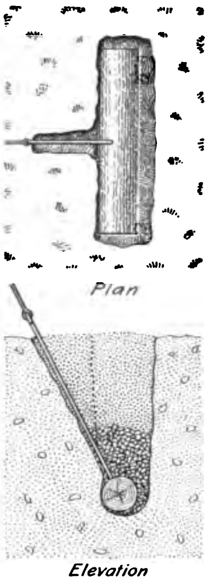


FIG. 47

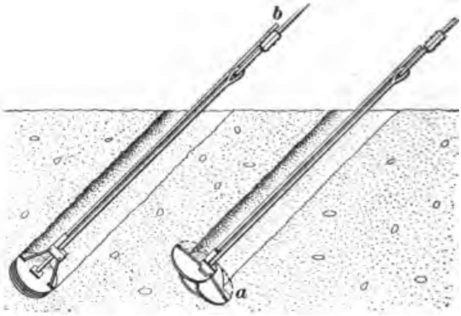


FIG. 48

26. In many cases the guy stub is anchored as indicated in Fig. 50, which also shows the method of securing the strand to the stub. To prevent the strand from cutting into and thus

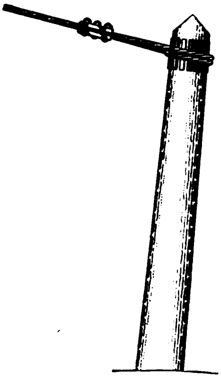


FIG. 49

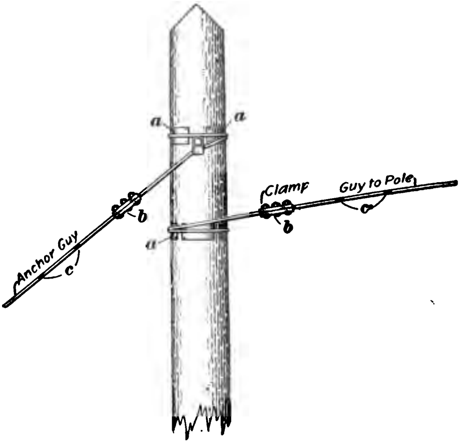


FIG. 50

weakening the pole, iron plates *a*, known as ***strain plates***, are used. The strand is passed twice around the pole and secured by means of one or two clamps *b*, the free end of the strand being fastened beyond the clamp with wrappings of iron wire *c*.

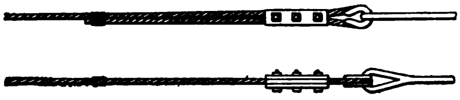


FIG. 51

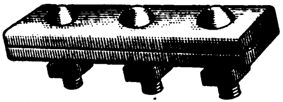


FIG. 52

This method of fastening a strand is clearly shown in Fig. 51; the link at the right being the end of an anchor rod. The ***three-bolt clamp*** used for securing a guy strand consists of two plates, each having two grooves for engaging the strand; the plates are clamped together by the clamp shown in Fig. 52. When lack of space prevents anchoring a stub, a decided rake is given to it and it is held in place by logs, as shown in Fig. 53, a method known as ***cribbing***.

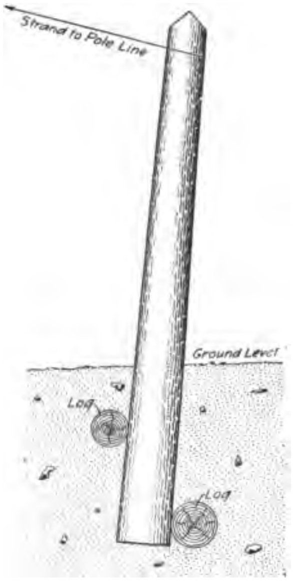


FIG. 53

27. Fig. 54 shows a method of guying the poles at a 90° turn and of head-guying poles near the corner so as to relieve the tops of the corner poles of most of the stress caused by the pull of the cable. Fig. 55 shows a method less desirable than that shown in Fig. 54 for accomplishing the same purpose. If the anchor stub shown in Fig. 54 cannot be firmly secured, the corner can be guyed as shown in Fig. 56. In every case the support, or messenger strand, is dead ended when approaching a corner at the first pole that has a head guy, as is indicated by the letters *DE* in the illustrations.

28. When support strands of different sizes are dead ended both ways in a pole line, the pole top at which the ends occur should be head-guyed to take the excess stress of the heavier strand, as indicated in Fig. 57. The support strands can be

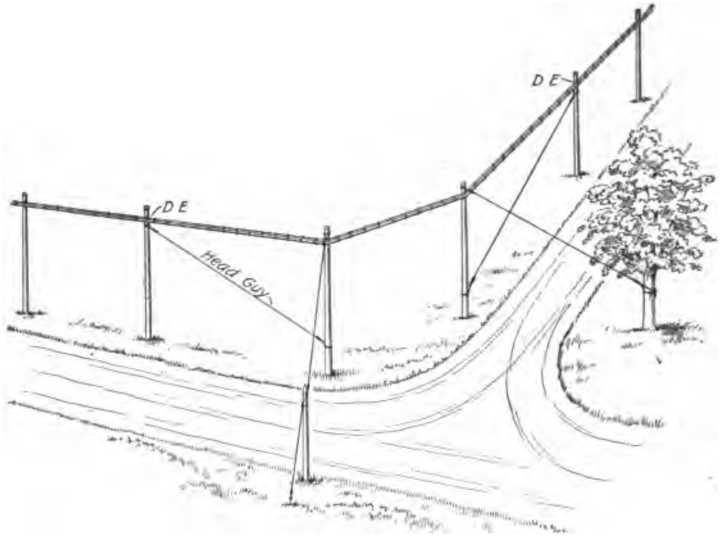


Fig. 54

carried straight across a square corner and the guys so arranged that the cable can turn on the strands instead of at the poles, as is indicated in Fig. 58, view (*a*), showing the method when

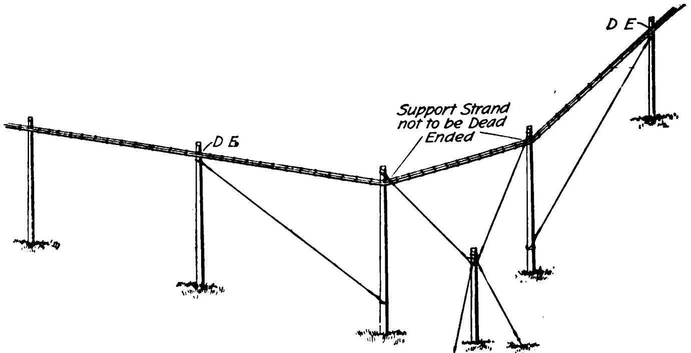


Fig. 55

one of the pole lines continues beyond the corner and view (*b*) for pole lines that are not continuous.

29. When the pole at the head of a cable line cannot be guyed, an extra-heavy pole can be reinforced by cribbing or set in concrete, and neighboring poles can be head-guyed to share the stress, as indicated in Fig. 59. If more than one heavy cable terminates at the same pole, recourse may be had to one of the methods indicated in Fig. 60, the method shown in (*a*) being preferable to that in (*b*); in both cases the guys must be extra heavy. Fig. 61 shows a method of guying a support strand away from an obstruction or to keep it from overhanging

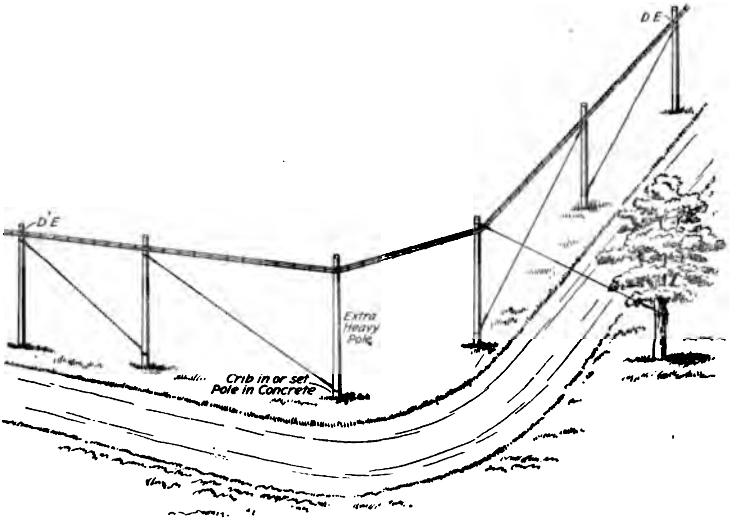


FIG. 56

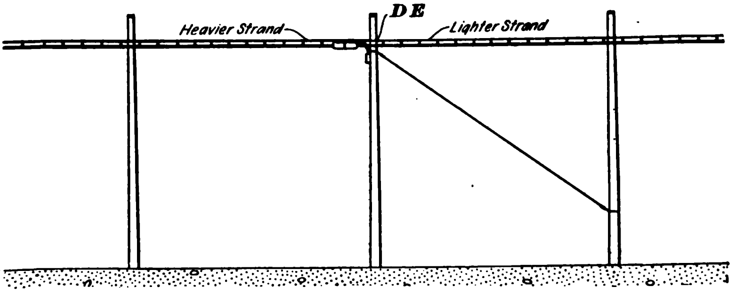


FIG. 57

private property. A clamp *a* on the messenger strand prevents the guy thimble from sliding on it.

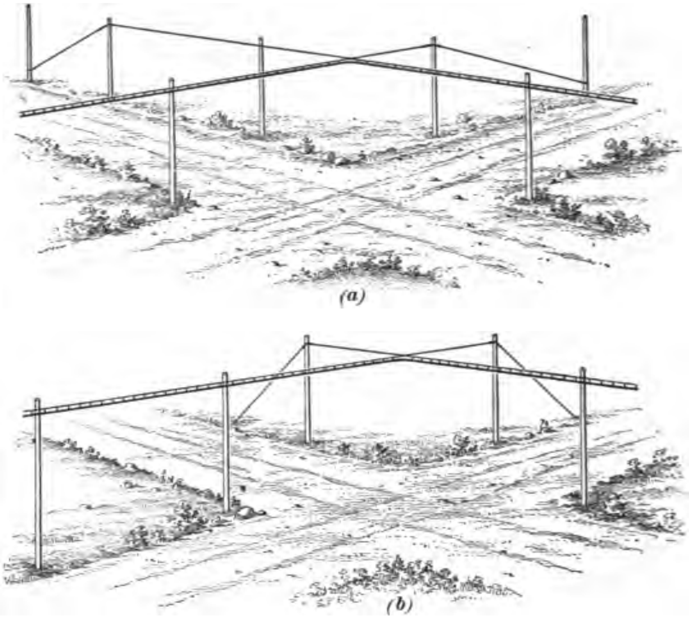


FIG. 58

30. If the corner pole at a square turn cannot be guyed, an extra heavy pole can be cribbed or set in concrete and an additional pole set near it in the line each way (short spans) for head-guying the pole next in line; this method is indicated

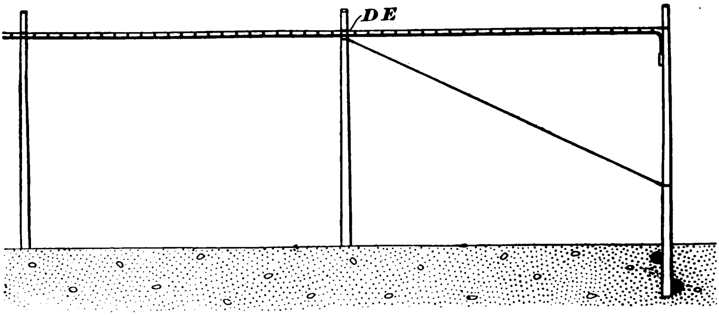


FIG. 59

in Fig. 62. On grades frequent head guys are advisable, as in Fig. 63 (*a*), to prevent all the poles sagging down the hill. Such guys at the two poles nearest the top of the grade are generally enough on other than steep grades. A marlin tie, view (*b*), should be placed in the middle of every fifth span on normal grades and every third span on steep grades.

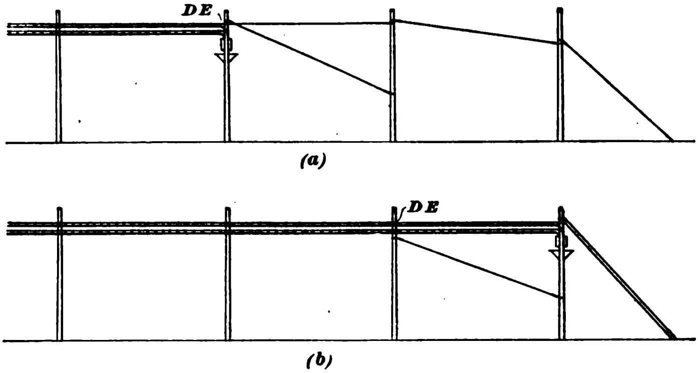


FIG 60

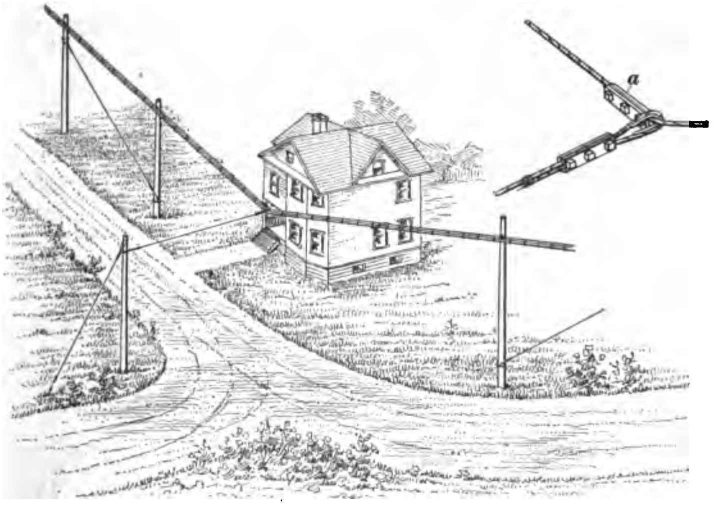


FIG. 61

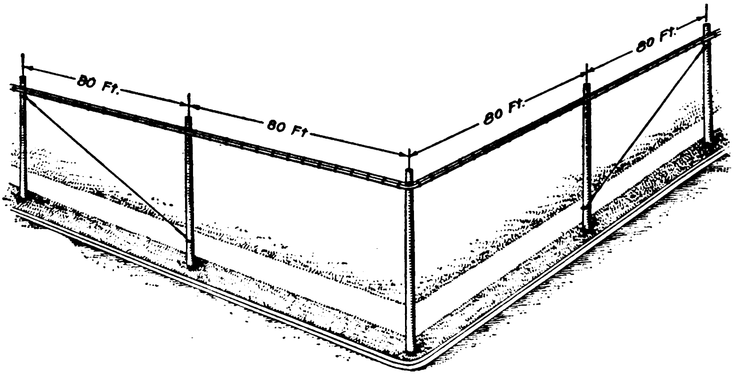


FIG. 62

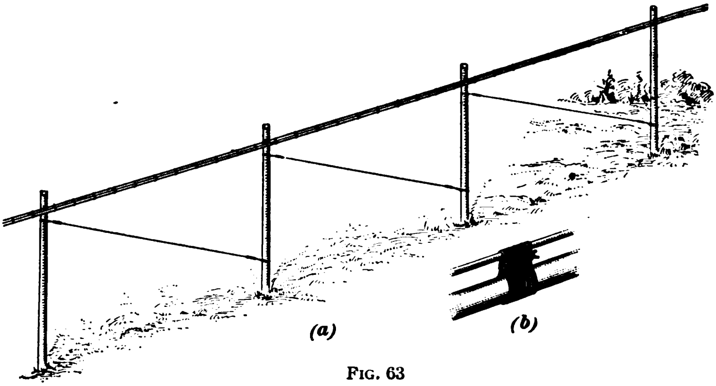


FIG. 63

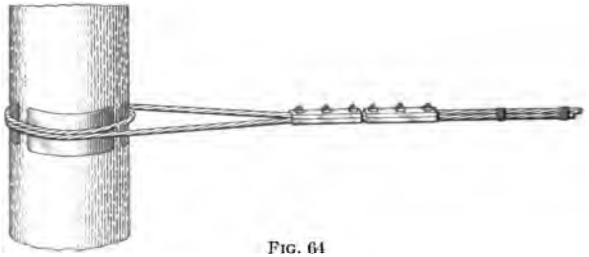


FIG. 64

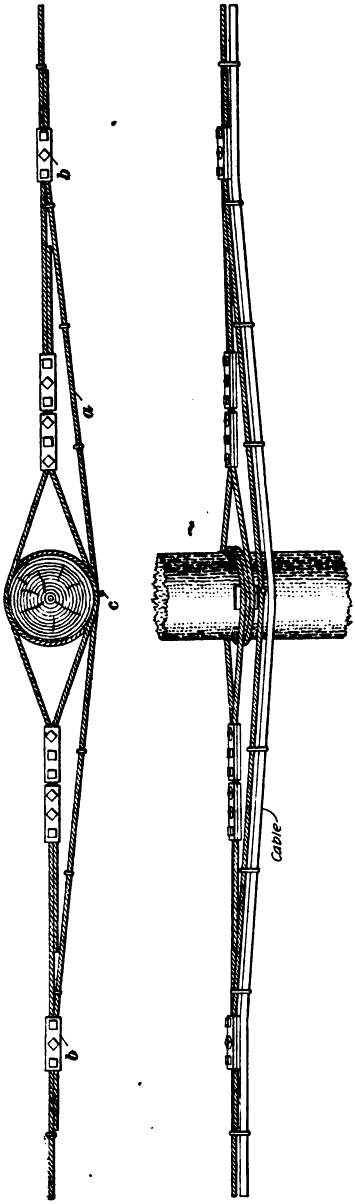


FIG. 65

31. The size of the support strand depends on the weight of cable to be supported. The cable most commonly used for town and city distribution is composed of No. 22 or No. 19 Brown & Sharpe gauge copper wire. A messenger strand $\frac{1}{4}$ inch in diameter can be used to support a No. 22 gauge cable of 25 pair, a $\frac{3}{8}$-inch strand can be used for a similar cable of 100 pair, a $\frac{7}{16}$-inch strand for 200 pair, and a $\frac{1}{2}$-inch strand for still larger cable. No. 19 wire being about double the weight of No. 22 per foot, No. 19 gauge cable can have only about half as many pairs for each diameter of strand.

32. At the end of the line, the strand is attached as shown in Fig. 64; it is turned two or three times around the pole over strain plates and held by one or two clamps, depending on the size of the strand. Wherever the strand changes size along a cable run, both strands should be dead ended, as shown in Fig. 65. For heavy cable a piece of strand *a* held by clamps *b* and a lagbolt *c* is used to support the cable in passing the pole. The messenger strand, even when of uniform size, should be dead ended both ways on straight runs at points approximately 1 mile apart and on all turns of more than 35 degrees.

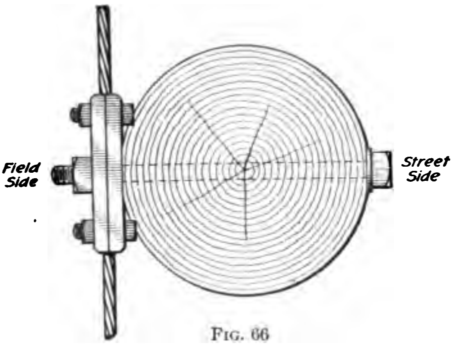


Fig. 66

33. At poles where the strand is not dead ended it is attached as shown in Fig. 66. A standard three-bolt clamp with the center hole enlarged to receive a through bolt is secured thereby against the side of the pole and serves to hold the strand. At bends in the line, a piece of strand should be wrapped around the pole, as indicated in Fig. 67, and clamped to thimbles *a* on the messenger strand. This auxiliary strand should be drawn tight enough to take part of the stress from the through bolt. The form of the guy thimble for use in this and other similar places is shown in Fig. 68. The inner surface of the thimble is smooth and rounded so as not to injure the messenger strand.

34. After the messenger strand is in place it is tightened by drawing up the guys with a block and tackle. The guys are clamped when the sag in the strand is approximately as follows:

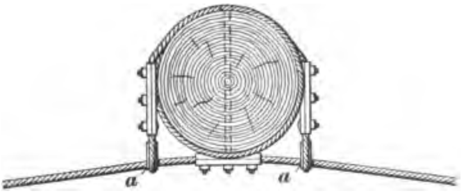


Fig. 67

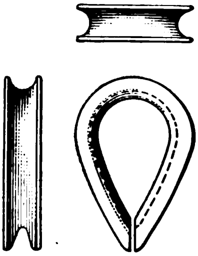


Fig. 68

LENGTH OF SPAN FEET	SAG INCHES	LENGTH OF SPAN FEET	SAG INCHES
80	16	140	40
90	20	150	44
100	22	160	54
110	26	175	62
120	30	200	82
130	34		

35. The cable rings, Fig. 45, are placed by a man in a cable car riding the messenger strand as shown in Fig. 69. The two lips of the ring are clamped around the strand by a special form of plier, two views of which are shown in Fig. 70. The standard size and spacing of cable rings is as follows:

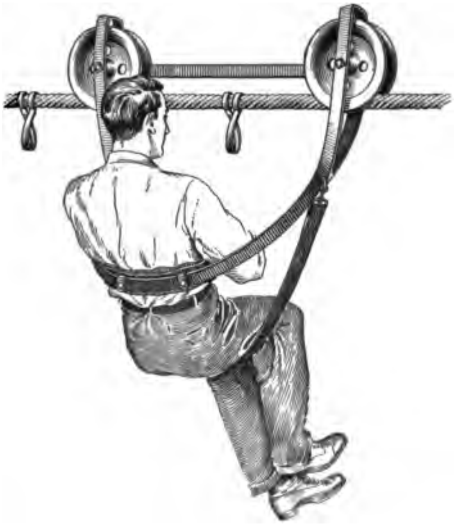


FIG. 69

2-inch rings 20 inches apart for cables up to 100 pair No. 22 B. & S.
2½-inch rings 16 inches apart for cables up to 200 pair No. 22 B. & S.
3-inch rings 14 inches apart for larger cables.

If the cable is of No. 19 B. & S. wire, the number of pairs is one-half as many in each case.

36. Placing Cable.—The man who places the rings threads a small manila rope through them as he travels along the strand, and this rope is later used to draw through a larger rope for pulling in the cable. If the cable is 150 pair of No. 22 gauge, 75 pair of No. 19, or larger, an additional pole step carrying a piece of gas pipe to serve as a roller is placed immediately below the strand, as shown in Fig. 71, to facilitate pulling the cable. The man who places the rings and roller also attaches by iron wire or marlin ties, as shown in Fig. 72, a hollow lead

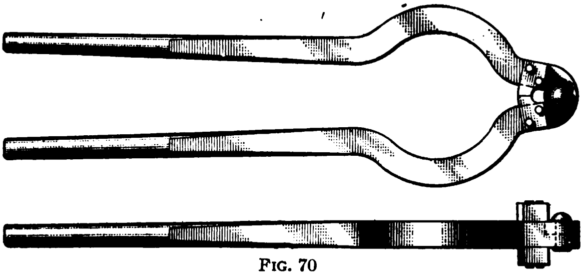
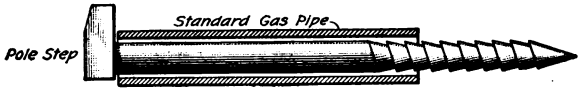


FIG. 70

cylinder, or sleeve, with dimensions as given in Table I, on the strand at all poles where cable terminals will be located and



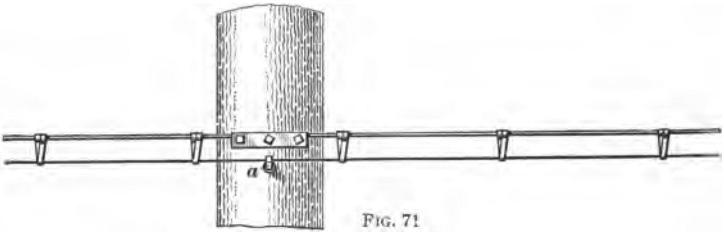


FIG. 71

tap splices made. The cables are usually called 100-pair, 200-pair cables, etc., but a few more pairs than these are included

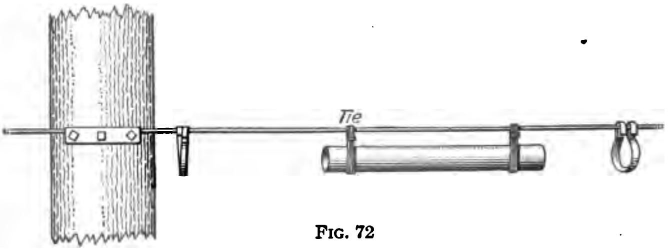


FIG. 72

in the make-up of the cable, as indicated in Table I. The function of these sleeves is to cover the completed splice, as explained later.

37. Fig. 73 shows the method of pulling in large cable. The wooden reel on which the cable is received is mounted so that it can turn freely, as on the axle of a special cart, and is placed about 30 feet from the pole where work is to begin. Pulley blocks *a* are attached to a temporary strand leading to the top of the pole and possibly one or two similar blocks are attached to the messenger strand near the pole. These blocks carry rollers over which the cable rides smoothly and easily into the rings. Methods of attaching the pulling-in line to the end of the cable are shown in Figs. 74 and 75. In Fig. 74 the end of the cable is enclosed in a wire basket-like device

TABLE I

DIMENSIONS OF SLEEVES FOR CABLES

No. of Pairs in Cable	Straight Splices			Y Splices for Taps					
				No. 19 B. & S.			No. 22 B. & S.		
	No. 19 B. & S.	No. 22 B. & S.	Length Inches	16-Pr. Tap	26-Pr. Tap	Length Inches	16-Pr. Tap	26-Pr. Tap	Length Inches
	Diameter Inches			Diameter Inches			Diameter Inches		
26	1¼	1	15	1¾	1¾	17	1½	1½	17
31	1¼	1¼	15	1¾	1¾	17	1½	1½	17
41	1½	1¼	15	1¾	2	17	1½	1¾	17
51	1¾	1½	17	2	2	17	1¾	1¾	17
61	1¾	1½	17	2	2¼	17	1¾	1¾	17
76	2	1½	17	2¼	2¼	17	1¾	2	17
101	2¼	1¾	20	2½	2½	20	2	2	20
152	2½	2	20	2¾	2¾	20	2¼	2¼	20
202	2½	2¼	20	2¾	2¾	20	2½	2½	20
303	3½	2½	*20	3½		22	2¾	2¾	20
404		3	22				3	3	22

*For a straight splice on a 300-pair No. 19 B. & S. cable, use a 22-inch sleeve.

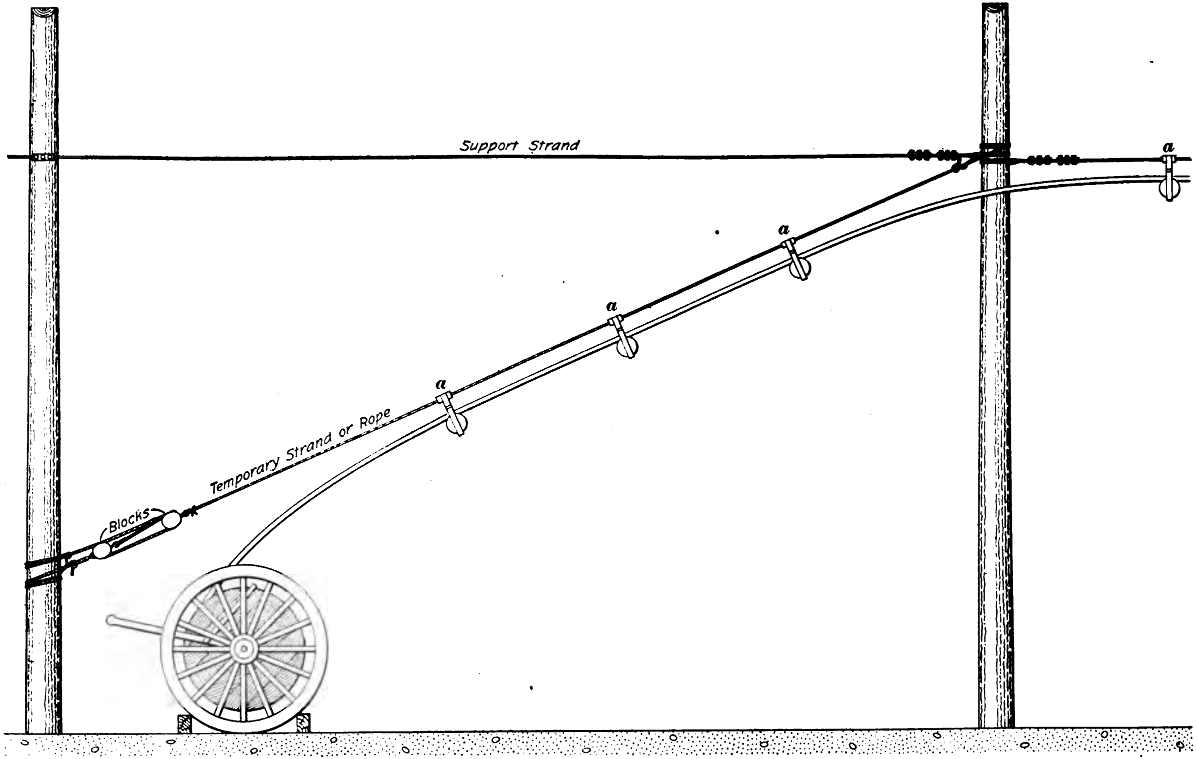


FIG. 73

that grips it tightly when the cable is pulled. The end of the device is bound to the cable by tape. The ends of the large cables are protected by rawhide collars. To make the hitch

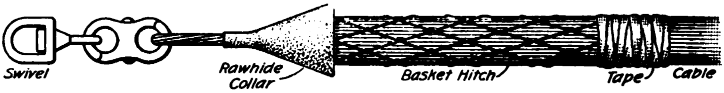


FIG. 74

shown in Fig. 75 the sheath is removed from the end of the cable and the wires are bent back and securely bound together with iron wire or marlin to form a loop.

38. Fig. 76 shows the other end *a* of the pulling-in line, to which the necessary force can be applied by a team of horses or a gang of men. At poles where bends occur, small pulleys, called *boosters*, are attached when large cables are to be pulled. These boosters serve to keep the cable from rubbing against the pole or to prevent it from pulling away from the pole, according to the nature of the bend. Ordinary pulley blocks or a wrapping of rope or burlap well greased serves the same purpose for small cable.

39. To facilitate the sliding of the cable through the rings, the end is well lubricated when entering the rings. Care must be taken to prevent the formation of kinks, to keep the cable running smoothly, and to see that the lead sheath is not damaged by friction. Cables should not be pulled around corners where the angle between strands is over 35°, but should be pulled to the corner from each direction and the ends spliced. After the operation of pulling the cable is completed, all of the auxiliary apparatus, such as the temporary strand used in starting the cable, the blocks and pulleys, and the wrappings of burlap around corner poles, should be

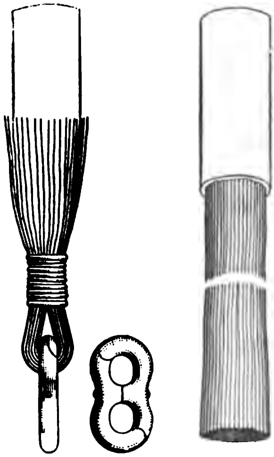


FIG. 75

removed and a thorough inspection made of the line to see that rings have not been displaced or other permanent equipment disarranged.

BLOCK CABLE

40. **Block cable** is the name given the cable that connects the terminals used in block wiring with the underground cable in the subway. The block cable is carried from the terminal along the walls of buildings, the tops of fences, or short poles on the rear boundary lines between lots to a point where it enters an iron pipe about 3 inches in diameter and is carried to the subway. The cable is fastened to brick walls by means of expansion shields, Fig. 16, the same as those used for bridle wires. The same shield can be used to support both a cable clamp and a bridle ring, as indicated in Fig. 77. Fig. 78 shows a standard cable clamp.

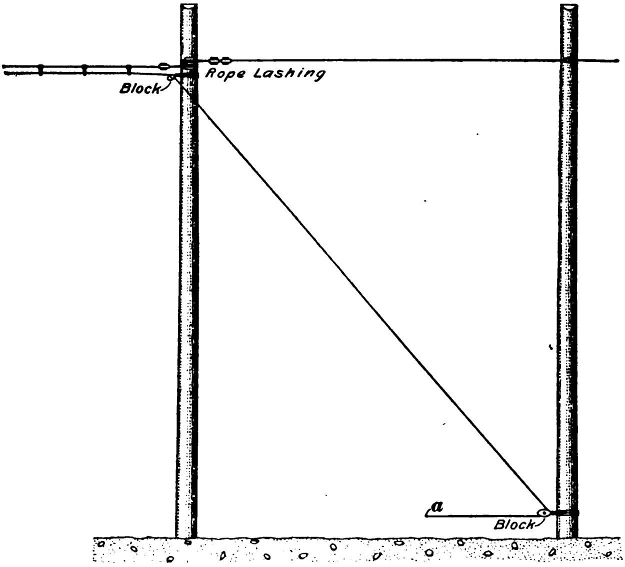


FIG. 76

41. Cables should be run horizontally or vertically along the walls of buildings rather than diagonally. At *a* in Fig. 79

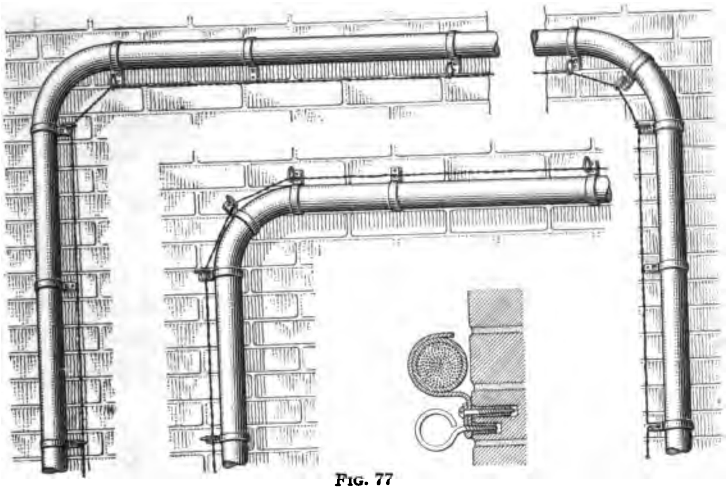


FIG. 77

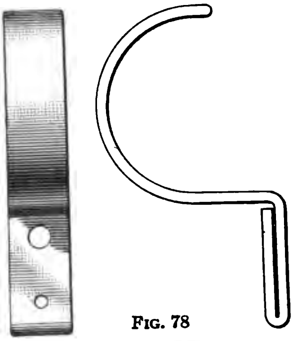


FIG. 78

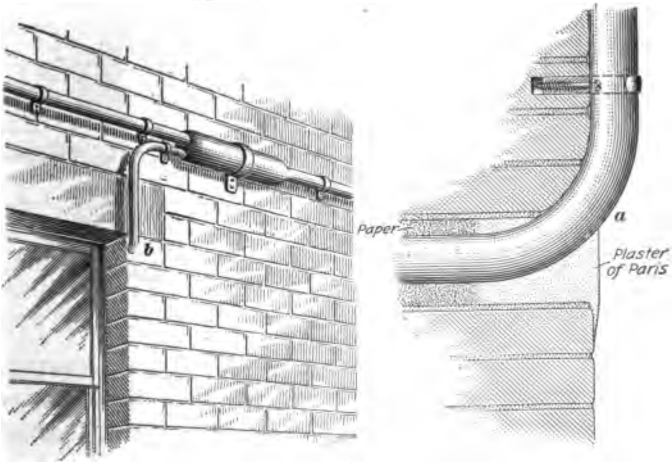


FIG. 79

is shown the method of bending a cable and entering it in an opening in a brick wall, the opening then being sealed as indicated. At *b* is shown how a branch, or tap, cable is entered in

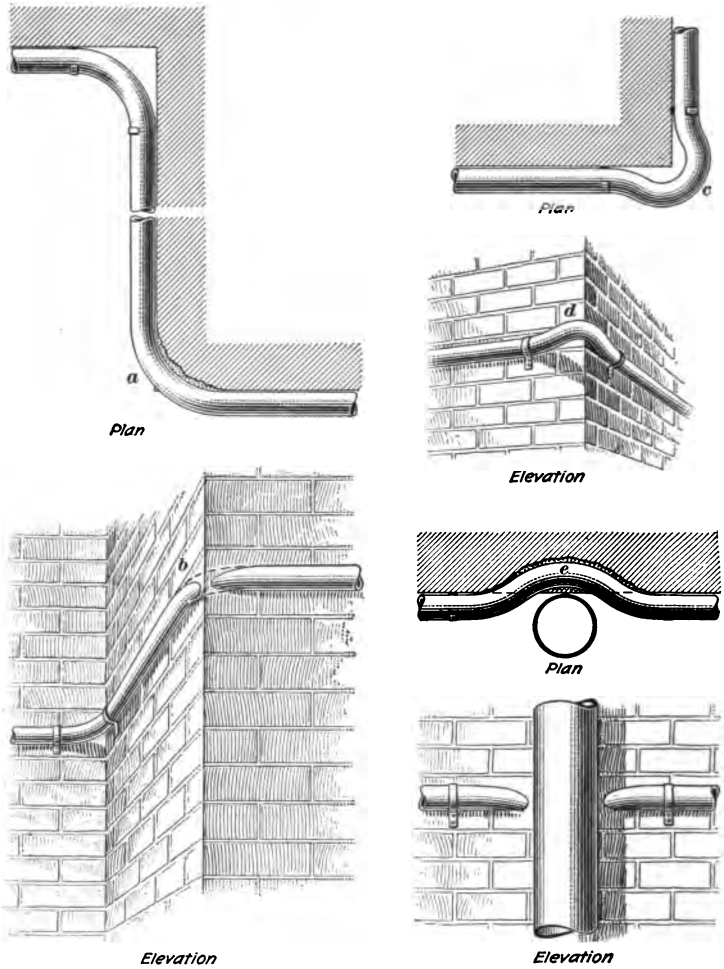


FIG. 80

a brick wall. In Fig. 80 at *a* in plan and at *b* in elevation is shown the method of running a cable around the corner of a masonry wall. At *c* and *d* is shown a method of looping a

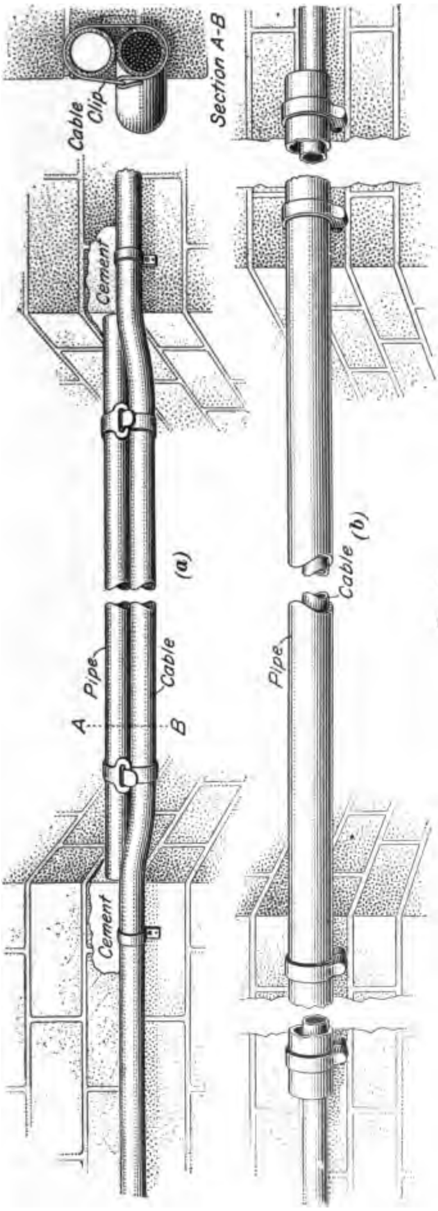


FIG. 81

cable so that it will be free from sharp corners, and at *e* the approved method of passing a vertical obstruction near a brick wall by chipping a channel behind the obstruction. Fig. 81 shows two ways of supporting a cable across the space between two buildings; in (*a*) the cable is shown suspended from a pipe, the ends of which are cemented in the two walls, and in (*b*) it is shown run through a pipe resting in *dog clamps* driven into wooden plugs in holes in the brick or stone walls, as indicated in Fig. 82.

42. Fig. 83 (*a*) shows a method of attaching a cable to a ceiling carried on I beams between which is a filling of cement and ashes. Holes are drilled through the outer portion of the ceiling and in each hole is driven a nail that will bend easily and to the head of which is attached a piece of annealed iron wire, as indicated in view (*b*). The wire is then wrapped around the cable and the ends twisted together. In view (*c*) is shown an attachment to a firebrick wall or ceiling by means of *toggle bolts*, the action of which is apparent from the illustration.

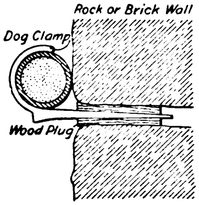


FIG. 82

43. Block cables mounted on back fences are preferably carried on top or immediately under the cap board, as indicated in Fig. 84. The run should be laid out to avoid fire escapes, doors, and other obstructions. Along walls the cable should be mounted against the brick rather than against the stone foundation wall below. If branches are to enter a basement in the manner shown in Fig. 79, the main cable should be mounted directly over the basement windows; otherwise, main cables should run directly under the sill of the first-story window.

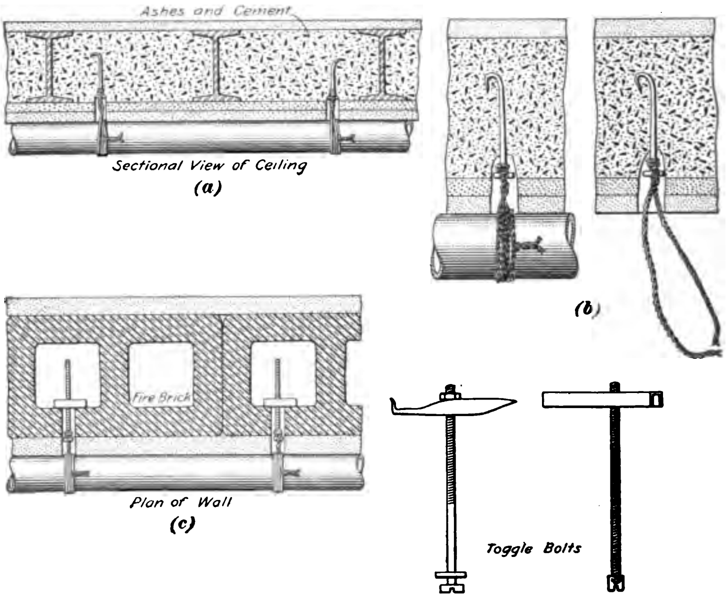


FIG. 83

Vertical runs should be as close to a window casement as may be without loosening bricks or interfering with the operation of the shutters. In no case should a vertical cable be mounted near the corner of a building. In basements, cables should be mounted against brick or stone walls rather than on plaster ceilings. Cables must not be placed in contact with the iron framework of buildings, with gas or water pipes, or other grounded conductors, because of the probability of electrolytic action that would be caused thereby. Cables should preferably be accessible at all points.

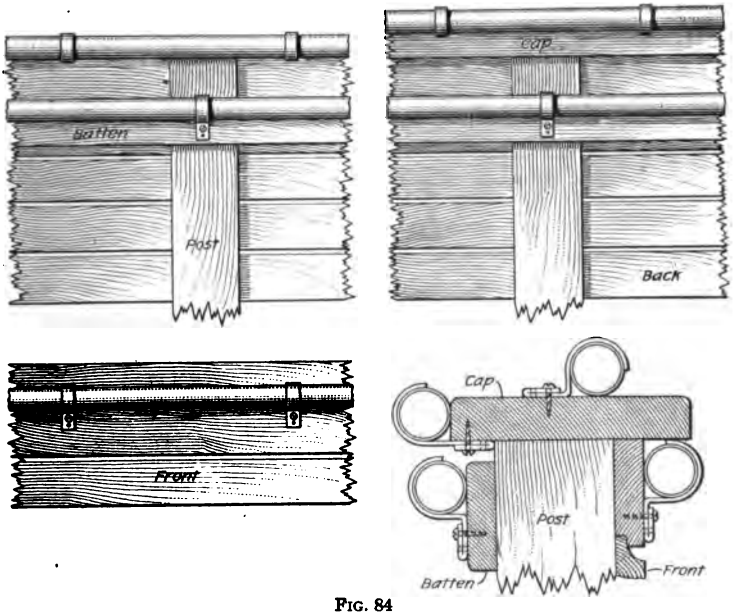


Fig. 84

HOUSE CABLES

44. On entering a building a cable should be led directly to a cable terminal, which should be of the protected type for aerial and block cables; unprotected terminals are satisfactory for underground cables. Connections with the house cables are made in this terminal.

The vertical riser cables inside of buildings can be installed in conduits, in elevator shafts, or in special wire shafts. Conduits are preferable to elevator shafts for small cables in buildings less than twelve stories high, as protection from mechanical injury is thereby afforded. For large cables and for taller buildings, special wire shafts are desirable. For best telephone service, these shafts should not contain electric-light or power wires, or pipes for steam, gas, or water. When conduits are used, the sizes should be as given in Table II.

45. When riser cables are installed in a shaft, they should be spliced in the cellar or on the roof and then raised or lowered into position and permanently attached either to the wall or to support wires. Fig. 85 (*a*) shows the approved method of suspending a support wire from the top of a shaft, and (*b*) shows a turnbuckle for making adjustments. Fig. 86 shows in views (*a*), (*b*), and (*c*) the method of attaching a cable to its support wire. Short pieces of galvanized iron wire *a* are forced between strands of the support wire. The cable is raised or

TABLE II

CONDUIT FOR TELEPHONE CABLES

Number of Pairs	Size of Conduit		Number of Pairs	Size of Conduit	
	Silk and Cotton Inches	Paper Inches		Silk and Cotton Inches	Paper Inches
11	¾		101	1½ to 2	2
16	¾	1	121	2	
21	1	1	126		2
26	1	1	151	2	2
31		1 to 1¼	202	2	2½
41	1 to 1¼	1¼	303		2½
51	1¼	1¼	404		3
61	1½	1½	505		3
76	1½	1½	606		3

lowered into place by means of a rope and fastened temporarily with marlin ties *b*, after which the permanent iron ties are wrapped around the cable and the support wire and secured. The rope is then removed. Floor-tap splices appear as in view (*c*).

46. Pull boxes, similar to those used in electric-light wiring are placed at the ends of conduit runs for convenience when pulling in cables. From the ends of the conduits on each floor to the terminal boxes the cables can be carried behind heavy molding. Molding can also be used to conceal wires between terminals and telephones.

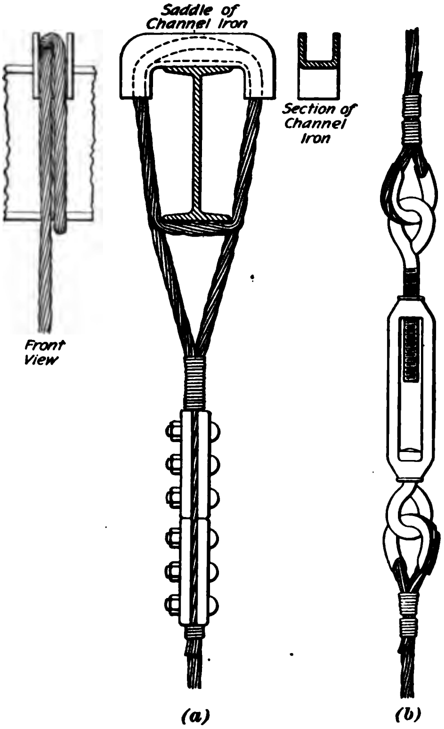


FIG. 85

47. A splicing diagram such as usually furnished to the construction foreman is shown in Fig. 87. For the sake of economy, splices are usually made only at every third floor, as indicated, and the taps for the floors above and below are placed in the shaft parallel with the riser cable. The diagram is made to show the number of pairs to go to each terminal box, and the pair numbers should be painted or stenciled on the connection strips in the terminal box.

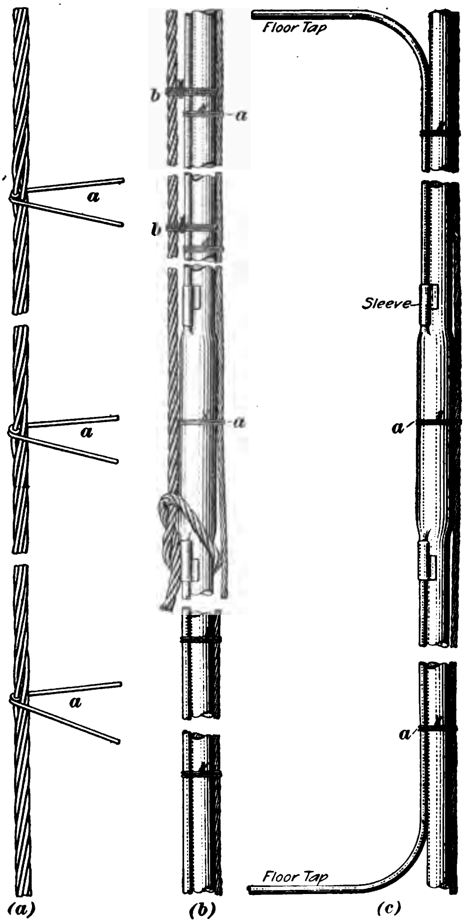

a
a
a
b
a
b
a
Floor Tap
Sleeve
a
a
Floor Tap
(a)
(b)
(c)

FIG. 86

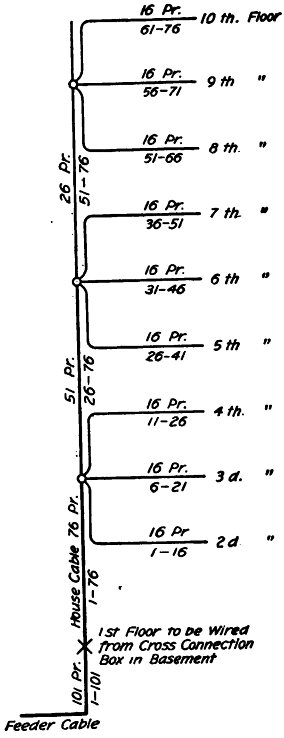

16 Pr. 61-76 10 th. Floor
16 Pr. 56-71 9 th "
16 Pr. 51-66 8 th. "
16 Pr. 36-51 7 th "
16 Pr. 31-46 6 th "
16 Pr. 26-41 5 th "
16 Pr. 11-26 4 th. "
16 Pr. 6-21 3 d. "
16 Pr 1-16 2 d "
26 Pr. 51-76
51 Pr. 26-76
House Cable 76 Pr. 1-76
1 st Floor to be Wired from Cross Connection Box in Basement
101 Pr. 1-101
Feeder Cable

FIG. 87

MAKING AND SPLICING PAPER-INSULATED CABLES

GENERAL PROCESS OF MANUFACTURE

48. Fig. 88 shows samples of lead-covered, paper-insulated telephone cables, some of the lead sheath being removed in each case so as to show the interior. The wires in the cable are nearly always either No. 22 or No. 19 Brown & Sharpe gauge, each wrapped spirally with dry-paper insulating ribbon. The insulated wires are drawn in pairs from reels and twisted uniformly in a machine. The pairs are then formed into a cable and wrapped with paper in another machine, after which the stranded cable is rolled onto a portable iron reel. Tests are next made for defective insulation, all defects are repaired, and the cable then baked in an oven. After the baking, the cable is fed into the lead press, or sheather, by which a mixture of lead and tin that has cooled to almost a solid state is forced by hydraulic pressure through a die surrounding the cable, so that the cable emerges completely sheathed and is wound on shipping reels. The cable is again tested before shipment, for grounds, crosses, and opens; if defective, the sheathing is stripped off and repairs are made. If none of these defects exists, the cable is tested for capacity, insulation, resistance, and conductivity, after which the ends are cut off and sealed by soldering.

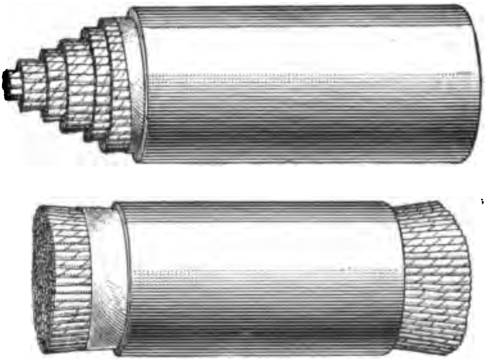


FIG. 88

CABLE SPLICES

49. Cable splices may be considered in four classes, *straight splices*, *tap splices*, *Y splices*, and *potheads*. The **straight splice** is the simplest for two cables joined end to end. In making such a splice, a piece of lead pipe, or a *sleeve*, large enough to cover the joint as finally completed is slipped over one end and far enough onto the cable to be out of the way; the lead sheathing is then stripped from the ends to be joined. A strip of dry muslin is wrapped tightly around each cable close to the end of the sheath and is tucked under the sheath to protect the insulation on the wires. The exposed insulated wires are then treated with boiling paraffin at a temperature between 350° and 375° F., either by dipping the wires in the paraffin or by pouring it over them when the cable is too heavy to handle.

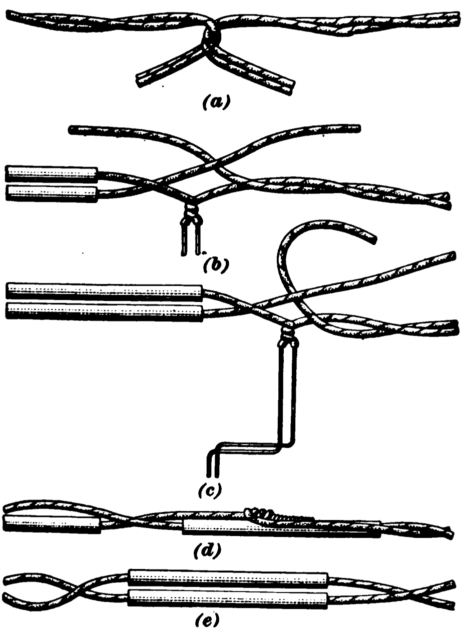


Fig. 89

50. Beginning near the center of each core, pairs are selected from each and hooked together as in Fig. 89 (*a*). Paper sleeves are slipped over the ends of the wires, which are then bared and twisted together as in (*b*) and (*c*). The twisting is done by forming a small crank of the wires as in (*c*) and turning it with the thumb and finger of one hand while holding the insulated wire at the other end of the twist with the thumb and finger of the other hand. The bared ends are then cut off,

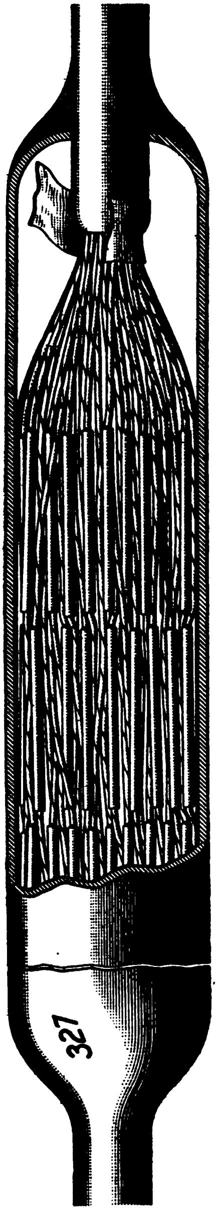


FIG. 90

leaving the twist about 1½ inches long with at least ten half turns of bared wire. Great care should be taken to cut the wires square across so as to leave no sharp edges to cut through insulation. The splice is then laid back against the wire and the sleeve is slipped over it as in (*d*), the finished splices of each pair appearing as in (*e*). All the other wires are joined in pairs in the same way, but care is taken to stagger the joints, as indicated in Fig. 90. When all the wires are joined, the bundle of joints is made compact, treated again with boiling paraffin, wrapped with muslin, and covered by slipping the loose sleeve over it. The edges of the sleeve are pressed down against the cable sheath and soldered to it, the joints being wiped as in plumbing work. The workman must then stamp his number on the outside, as he is held responsible for the splice. Fig. 90 is shown partly in section to give an idea of details as well as of the finished splice.

51. A **tap splice** is formed when wires of a terminal or tap cable are joined to those of a main cable. The method of making such a splice is indicated in Fig. 91 and the completed splice is shown in Fig. 92. A short piece of wire *a*, Fig. 91, is inserted so that the branch that continues in the main cable will be the same length as the other wires that are not tapped. For such a splice the sleeve must be

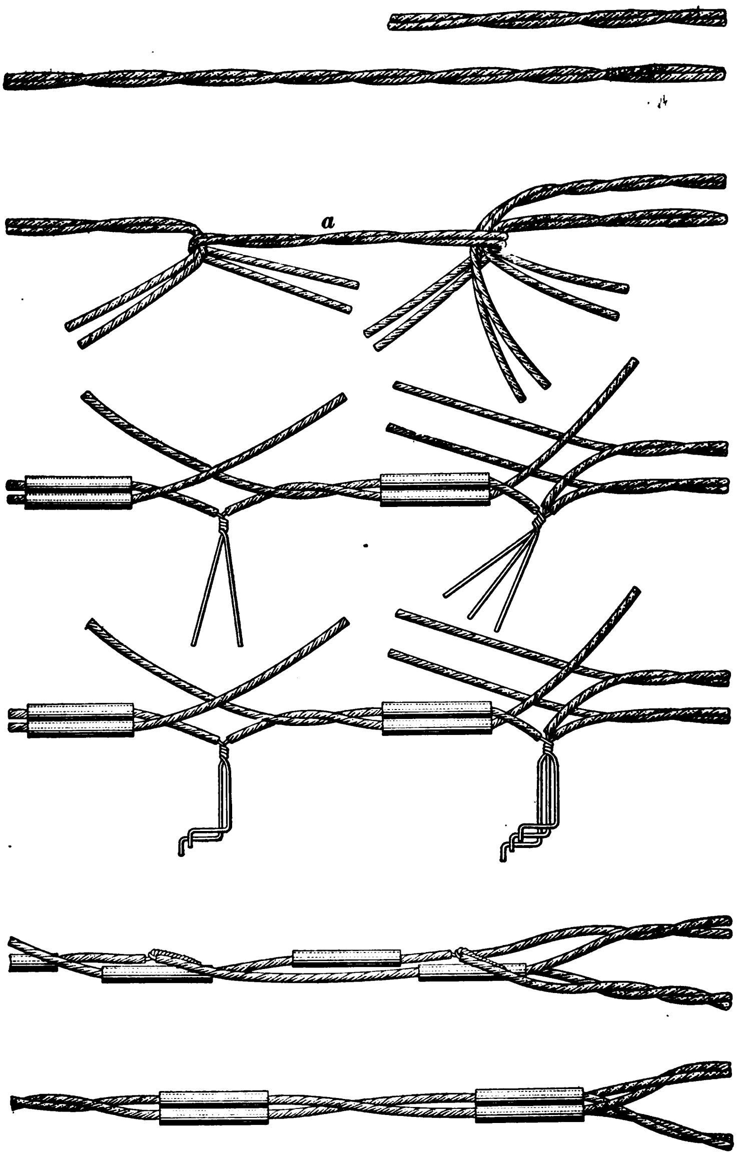


FIG. 91

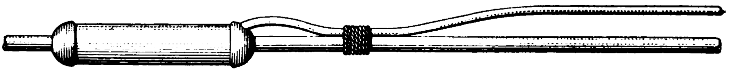


FIG. 92

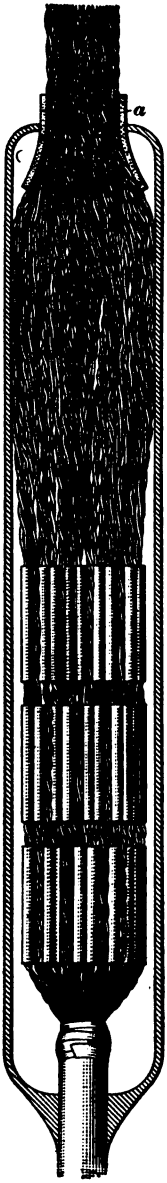


FIG. 93

placed near the point where the tap splice is to be located and the cable is then pulled through it; otherwise, a split sleeve will be necessary. After such a splice is finished, the branch cable is securely tied to the main cable about 6 inches from the splice, as shown in Fig. 92. The tie serves to relieve the splice from some of the mechanical stress that otherwise might be applied to it.

52. A **Y splice** is formed when a cable branches into two smaller cables. The individual splices may be made as straight splices or tap splices; that is, some individual pairs of the larger cable may be joined to a pair in one of the smaller cables and others may be joined to two pairs, one in each smaller cable, making connections with the same pair in the larger cable available at the ends of both the smaller cables. A Y splice is more difficult to make properly than either a straight splice or a tap splice.

53. A **pothead** is a splice made by joining the rubbercovered weather-proof insulated wires of an underground cable with the paper-insulated wires of an aerial cable. The process of making it is the same as that of making a straight splice, except that after the sleeve is soldered to the sheath of the aerial cable the splice is secured in an upright position and filled with hot insulating compound to within ½ inch of the top of the sleeve, adding more compound as it settles. A leather collar is placed around the wires under the top of the sleeve, and the sleeve is bent in against the leather to form a tight joint. Fig. 93 shows such a splice with the sleeve cut away to show the interior; the leather collar appears at *a*.

JOINT USE OF POLES

54. Economy can sometimes be effected by placing telephone conductors on the same poles with electric-light and power wires, a practice that is followed by some Bell companies, provided the poles carry no circuit with voltage exceeding the maximum voltage for which the protective apparatus on the telephone circuits is designed; these limiting voltages are as follows:

5,000 volts constant potential, neither side grounded.
700 volts constant potential, direct current, one side grounded.
7,500 volts constant direct current, series metallic circuit.
5,000 volts constant alternating current, series metallic circuit, or
10,000 volts in the same circuit if current is less than 7½ amperes.

55. The common practice when poles are to be used jointly is to reach a preliminary agreement as to the exact plans and specifications according to which the work must be done. This agreement covers the relative positions of the two classes of circuits and the auxiliary devices connected with each, as well as the precautions to be taken for the safety and convenience of the public and the employes of each company. Before doing such work, employes should obtain copies of the specifications and study them carefully; they should then comply to the letter with the specifications. Telephone employes should be particularly careful not to allow any part of the body to come in contact with electric-light and power wires carrying high-voltage currents unless absolutely necessary. If such wires must be handled, heavy gloves should be used and the rest of the body should be in contact only with dry wood or some other insulating substance.

Telephone and electric-light or power wires are never carried on the same cross-arms. The electric-light or power wires being mechanically the stronger and less likely to break, are usually mounted above the telephone wires. If a telephone wire breaks it does not then fall across a high-voltage wire. Moreover, telephone linemen do not then have to climb through the light and power wires on which the voltage may be dangerously high in order to reach the telephone wires. Climbing space must always be provided between the wires nearest the poles. Fig. 94 shows one arrangement and indicates some standard spacings.

56. Fig. 95 shows an approved arrangement on a pole carrying an aerial telephone cable and a terminal box for connecting subscribers' drop wires as well as electric-light wires

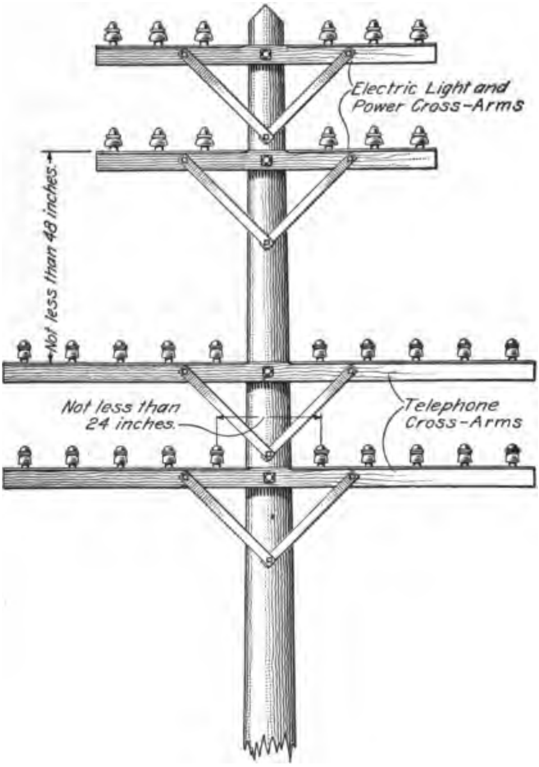


FIG. 94

and a lighting transformer. A guard arm is securely bolted to the pole a little above the messenger strand, and parallel with it, chiefly so that linemen cannot stand on the strand while working on the electric-light wires. The strand is always grounded at some point, and a lineman standing on it might complete through his body a circuit from an electric-light wire to the ground. If the vertical distance between the strand and the bottom of the lowest cross-arm carrying electric-light wires can be made 6 feet or more, the guard arm is unnecessary.

57. Fig. 96 shows the accepted plan when a pole carries electric-light and power as well as telephone wires, and indicates some of the limiting spacings. Properly insulated wire from the lighting circuit is carried down the side of the pole to the point where it leaves to pass out to the arc light. For arc lights, the insulated wire must be enclosed in conduit or insulating molding; for incandescent lights, it may be carried on insulators.

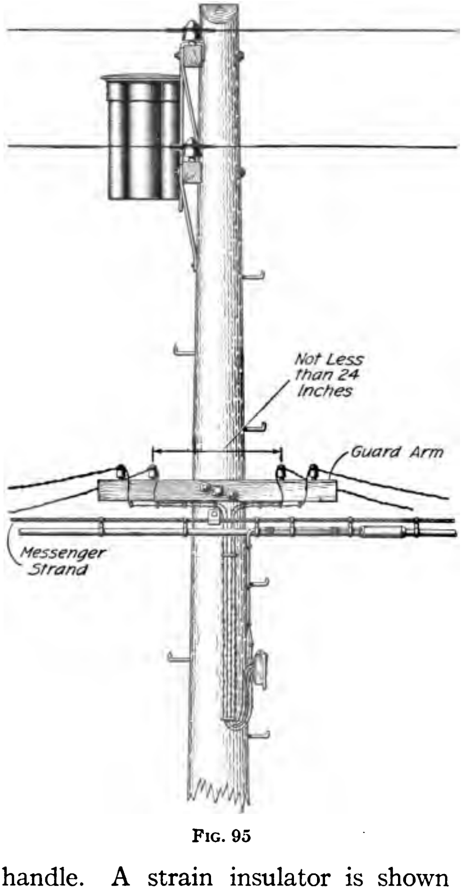


FIG. 95

58. A strain insulator is used in each guy strand attached to jointly used poles to insulate the guy so that pedestrians and animals will be safe in touching it. Without such insulation, an accidental cross might make the guy dangerous to handle. A strain insulator is shown in Fig. 97 (*a*) and in section in (*b*). The guy strand is attached to the steel eyes *a* and *b*, which extend into solid insulating compound *c* and are locked by metal rings; the two sets of metal parts are separated electrically.

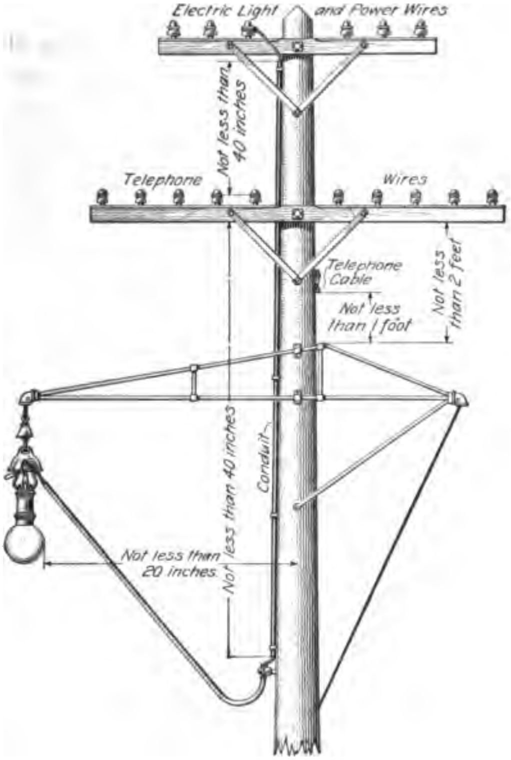
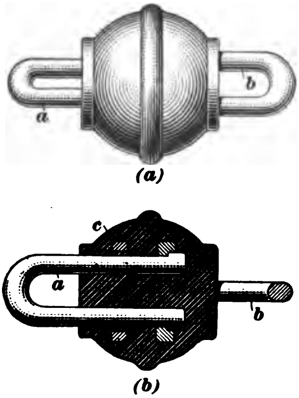


FIG. 96



(a)

(b)

FIG. 97

RESUSCITATION AFTER ELECTRIC SHOCK

59. Working around high-pressure electric circuits is more or less dangerous at the best, and accidental shocks may be received, especially if linemen become careless. Such shocks often only stun the victim and stop his breathing, which may be restored by prompt action before the victim suffocates.

60. The first step is to open the electric circuit or remove the victim from it with the greatest possible haste. The circuit can be opened by pulling a switch if one is convenient or by cutting a wire, using an axe or insulated pliers. If necessary to separate the victim from the conductor, use every precaution to avoid receiving a shock. The use of a dry coat, dry stick or board, or any other dry non-conductor will enable the rescuer to break the electrical contact with safety to himself. If it is necessary to touch the body before the circuit is broken, be sure that the hands are properly insulated either with rubber gloves, mackintosh, rubber sheeting, or other insulating covering. If none of these articles is available, stand on a dry board or some other dry insulating surface and if possible use one hand only. If the victim has been seized with convulsions causing him to grasp the wire with a clutch too firm to be easily broken, break the circuit by standing on a dry board and lifting the victim from the ground if possible, rather than by trying to break his grasp.

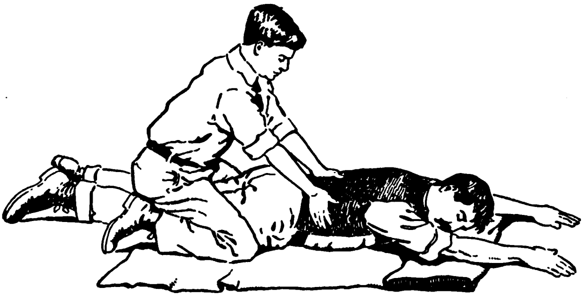


FIG. 98

61. As soon as the victim is free from the wire, send for the nearest doctor, and then proceed immediately with the following method of resuscitation:

Remove any foreign substances, such as false teeth or tobacco, from his mouth. Lay him face downwards with arms extended as straight as possible and with his face to one side, so that the nose and mouth are free for breathing. An assistant should draw the patient's tongue forward in the mouth and hold it to prevent it from closing the air passages. Kneel in a position to facilitate placing the palms of the hands on the muscles in the small of the back of the victim, with the thumbs nearly touching each other and the fingers over the lowest rib as shown in Fig. 98. With arms held straight, swing forwards slowly so that the weight of the body is gradually brought to bear upon the victim, as shown in Fig. 99. This operation should take from 2 to 3 seconds and must not be violent, otherwise the victim may be injured internally. The lower part of the chest and abdomen is thus compressed and air forced out of the lungs. Immediately swing backwards so as to remove the pressure, but leave the hands in place and return to the position shown in Fig. 98. The elasticity of the victim's chest causes the lungs to expand with fresh air. After 2 seconds swing forwards again and repeat the entire operation six or seven times a minute. A good rule, if no watch or clock is available, is to follow one's own respiration, swinging forwards with each respiration and

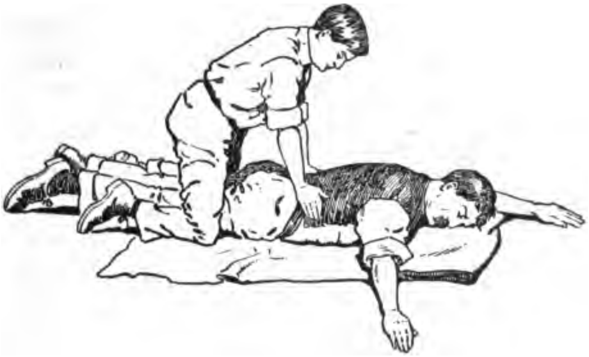


FIG. 99

backwards with each inspiration. While this is being done, an assistant should loosen the clothing about the patient's neck.

62. Continue this artificial respiration without interruption until a physician arrives. Even after natural breathing is resumed, a careful watch should be kept to see that it continues. If natural respiration stops, repeat the artificial respiration at once. It is sometimes necessary to continue artificial respiration for 2 hours or longer. An assistant should keep the victim's body warm by proper covering and use of hot-water bags. No liquid should be given until consciousness has been full regained.

63. A device, known as the *pulmotor*, has been developed, which, in addition to other functions, performs mechanically the operation described above. If a pulmotor can be obtained, it should be used instead of the manual method of resuscitation

UNDERGROUND PLANT

SUBWAY CONSTRUCTION

64. The most economical and satisfactory way of running telephone circuits through cities and large towns is in **underground conduit.** The circuits are then out of the way, free from mechanical injury, the useful life of cables is much

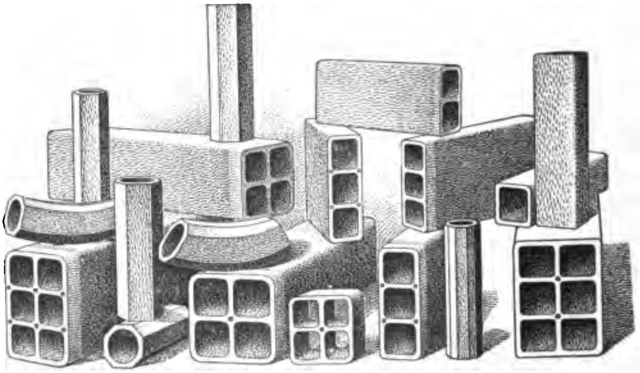


FIG. 100

prolonged, and unsightly overhead structures are avoided. A well-built conduit subway, if properly located, is nearly permanent and requires very little maintenance expense.

65. Conduit subways are usually built of clay tile, each tile containing from one to nine ducts. Fig. 100 shows a group of tile of the sizes ordinarily used in subway construction. Tile containing more than one duct are known as *multiple-duct tile.* Fig. 101 gives the plan of a subway and shows the location of manholes *a*, a single-duct branch to a pole *b* for connection to an aerial cable, and a branch *c* into a building; such branches are usually called **laterals.** A plan of this kind is given to the foreman and used by him as a guide for subway construction.

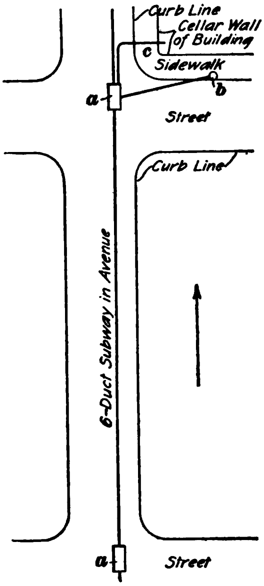


FIG. 101

66. Fig. 102 shows a trench during the construction of subway. The tile are laid on a foundation of concrete and subsequently covered with a roof of the same material. Fig. 103 shows the concrete construction more clearly. In this case the subway contains twenty ducts and is built up of two six- and two four-duct rows of tile. In Fig. 104 the grouping and arrangement of tile used in forming various sizes of subway ranging from two to twenty-four ducts are shown. The most desirable arrangement of ducts in a subway is not over four wide, as this arrangement facilitates entrance to the manholes, which are narrow in comparison with their depth. Fig. 105 shows the interior of a brick manhole and Fig. 106 that of a concrete manhole, these being the two usual constructions. A cast-iron frame at the top contains a hole large enough for a man to enter, and a suitable cast-iron cover is provided.

Branches, or laterals, such as those extending from the manhole to a pole or a building, are constructed either of single-duct tile or of wooden creosoted tubing, shown in Fig. 107, known as *Wyckoff tubing*. To facilitate the termination of the lateral at the pole, a 20-foot length of iron pipe containing a right-angled bend is used, as shown in Fig. 108; such a pipe is known as a *riser*.

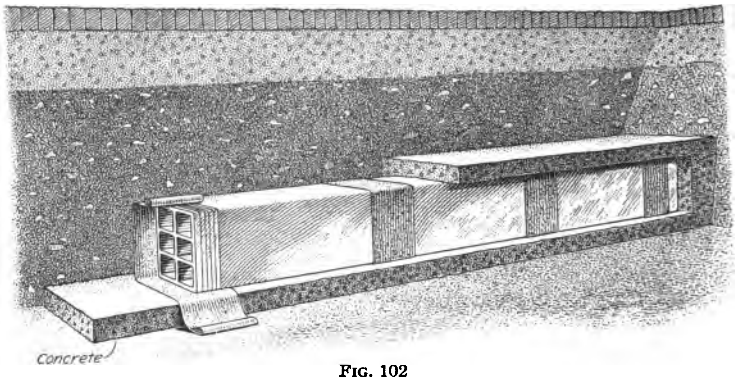


FIG. 102

67. Before starting the construction of a subway, a preliminary survey is made, and plans are drawn up showing the approximate location of the main subway and manholes and the measurements of all laterals. Usually the original plan has to be varied to avoid unforeseen subsurface obstructions, such as water and gas pipes, electric-light subways, etc. At least 6 inches of concrete or 12 inches of earth should separate telephone conduit and manholes from electric-light and power conduits. Information as to the approximate location of obstructions of this nature can usually be obtained from city records, and in general the telephone subway should be located on the side of the street freest from the plant of other companies.

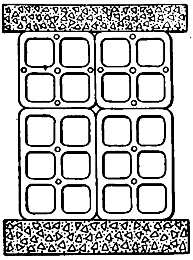


FIG. 103

68. If, for any reason, reliable city records are not available, test holes should be dug at intervals along the line of the proposed subway, and the desired information obtained in this way. Test holes dug at the site of proposed manholes will usually suffice. These holes serve the additional purpose of predetermining the character of the soil. If a stratum of rock is encountered, necessitating expensive blasting in excavating the subway trench, relocation of the subway on an adjoining parallel street may give the desired results at lower expense.

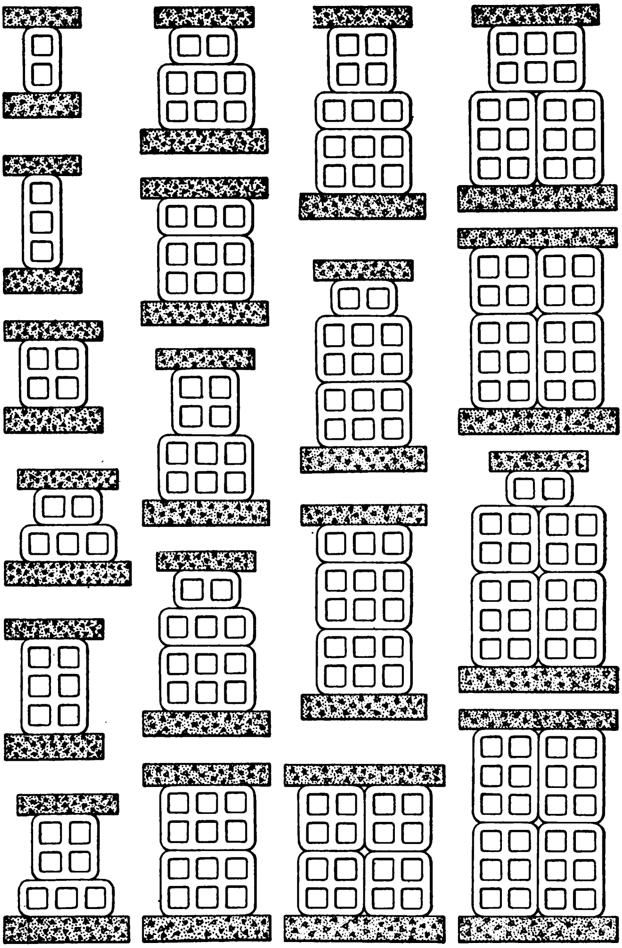


Fig. 104

In general, the center of a street should be avoided because of the possibility of damage to the conduit caused by subsequent construction of sewers or street railways; a position too close to the curb also incurs danger from exposure to surface drainage.

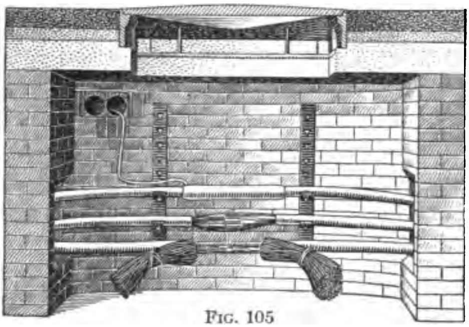


FIG. 105

The trench should be excavated about 4 inches wider than the tile. If the paving material can be used again, it should be preserved. If blasting is necessary, it should be done by an experienced man and in strict accordance with laws and ordinances. Damage to property may cause expensive litigation.

69. Manholes should be placed every 300 to 500 feet and located as nearly as possible at corners of intersecting streets or alleyways. The inside dimensions of manholes for various sizes of subway for straight runs without intersections are given in Table III. For intersected runs the same dimensions are used, except that the width of a manhole for a subway containing from seven to fifteen ducts is made 5 feet instead of 4. The excavation for a manhole must be large enough to provide

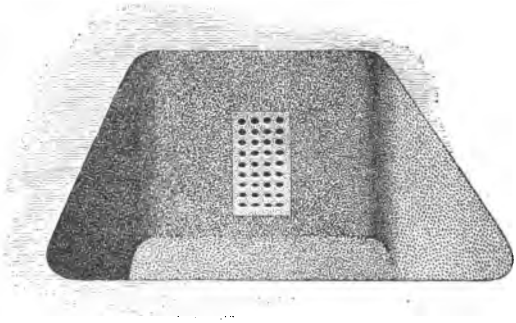


FIG. 106

for the thickness of the manhole walls and the roof in addition to the dimensions in the table.

70. Before laying the concrete base, a slope of at least 6 inches per hundred feet between manholes should be provided and the soil below the base should be smooth and hard to insure good drainage. The concrete may be mixed with Rosendale cement for use in dry soil, but concrete for damp or wet locations and for the manhole roofs should be mixed with Portland cement. Concrete should be used as soon as possible after it is mixed. The proportions by volume of the ingredients are as follows, enough water being added in each case to give the proper consistency: Portland cement, 1 part of cement, 4 parts of sand, and 8 parts of broken stone or gravel. Rosendale cement, 1 part of cement, 2.5 parts of sand, and 5 parts of broken stone or gravel.

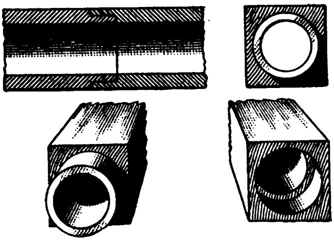


FIG. 107

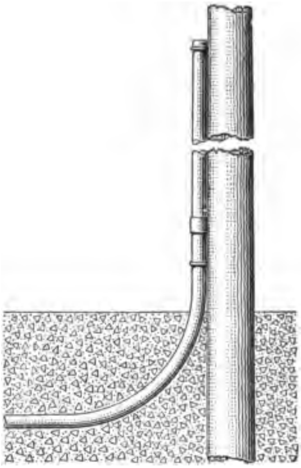


FIG. 108

TABLE III
DIMENSIONS OF MANHOLES FOR TELEPHONE SUBWAYS

Number of Ducts	Length Feet	Width Feet	Height Feet
1 to 6	4.5	3.5	4.5
7 to 15	6.0	4.0	5.0
16 to 24	8.0	5.0	5.5

Clay tile are heavy and must be handled carefully to avoid unnecessary breakage. Two men with pick handles thrust into opposite ends of a duct in each tile can handle it readily. As the tile are laid, their alinement is insured by dowel-pins in small holes provided in the ends of the tile for that purpose, as can be seen in Fig. 100. The joints between tile are wrapped with wet cheesecloth and then covered with a mixture of sand and cement as shown in Fig. 102. A layer of concrete is then placed over the top.

The brickwork in manholes should be laid by experienced bricklayers. Either Portland or Rosendale cement mortar may be used except for the roof, for which only Portland cement is approved. After the walls and roof are complete, the cover in place, and all concrete has set, the space around the wall is filled with earth, which is packed solidly in place with tamping bars.

71. A trench is made for a lateral the same as for a subway and the bottom is covered with a thin layer of concrete. If Wyckoff tubing is used, the ends are joined as shown in Fig. 107, and the tubing covered with a $1\frac{1}{2}$-inch creosoted plank to protect it from mechanical injury during subsequent excavations. If one-duct tile are used they are alined by means of dowel-pins and covered with concrete, as in a subway. In order to escape disturbance during work on the street paving, the tops of subways and laterals should be at least 2 feet below the surface of the street.

72. Pole laterals are preferably run in straight lines to the manholes, thus necessitating only one bend, but municipal regulations sometimes require all such runs to be either perpendicular to the curb or parallel with it. In this case, an additional iron pipe bend will be necessary at the point where the direction changes between the foot of the pole and the manhole. Other deflections from a straight run should be avoided if possible. If the length of the lateral is not over 100 feet, a 60° curve with a radius of 25 feet is permissible. For longer laterals up to 200 feet, the radius of a 60° curve should be at least 50 feet, and so on. If double curves are necessary, neither curve should depart more than 50° from the original path of the lateral.

A riser is usually made from a 20-foot section of iron pipe bent 90° on a curve with a radius of 30 inches. It is fastened to the pole by means of staples, as shown in Fig. 108.

UNDERGROUND CABLE

DRAWING IN CABLE

73. The cable is drawn into the ducts by means of a rope, which is pulled through from one manhole to the next, generally by means of either a *fish wire* or a *chain of short wooden rods*. The fish wire is usually No. 9 galvanized steel and is threaded through the conduits as they are laid. The rods are pushed into the finished conduit one at a time and jointed together until the chain reaches the next manhole, a process called *rodding the subway*. This process is slow; if the distance between manholes is comparatively short and the interior of the ducts smooth, a steel wire, usually No. 6 gauge, can sometimes be used instead of the rods.

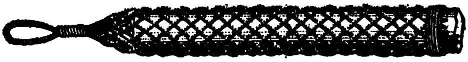


FIG. 109

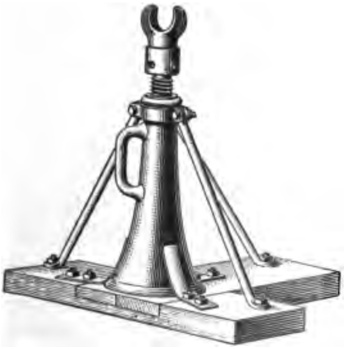


FIG. 110

74. In general, when the cable is to pass through a number of manholes, ducts having the same relative position in each section of the subway should be used. Usually the selection of a duct is made from the records in the office, but if this method is not possible, the foreman should carefully inspect the conditions in each manhole throughout the cable run and select a duct that will allow the cable to be placed on the manhole walls so as to cause the least possible interference with cables already in the subway.

The pulling-in rope is attached to the end of the cable in different ways, the most common being by means of a wire grip, as shown in Fig. 109. A galvanized-iron collar is placed over the end of the cable to protect it from injury. The cable reel is hung on a bar between jacks or other stationary supports

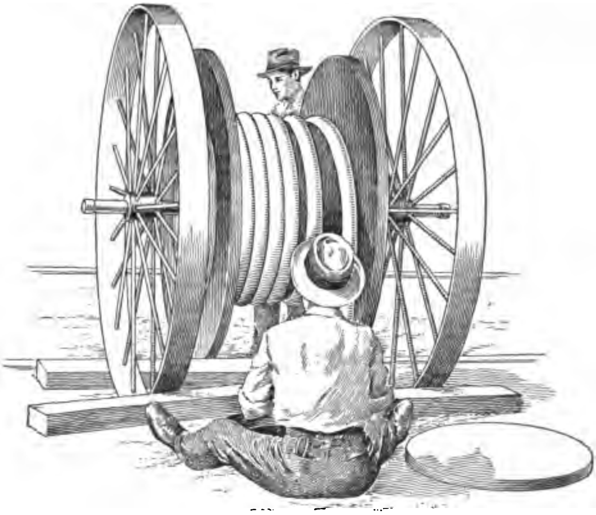


FIG. 111

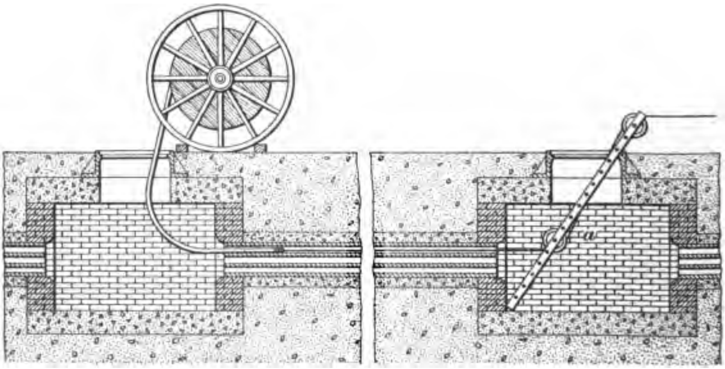


FIG. 112

or on the axle of a suitable cart. Fig. 110 shows a cable-reel jack, and Fig. 111 a reel mounted between wheels.

75. Fig. 112 indicates the process of pulling in a cable. The reel should be set and securely blocked so that the cable is in line with the duct opening. The cable should be guided so that it will enter the duct without a sharp bend, and it should be well lubricated at the point of entrance. Lubrication is usually provided by means of soft soap applied to the cable at the manhole opening. A man is stationed within the manhole to watch the cable and guard against the formation of kinks or the abrasion of the cable as it enters the duct. The method of handling the pulling-in rope in the manhole toward which the cable is being drawn is shown at *a*, the rope passing around two pulleys in a portable frame. The pulling is usually done by a team of horses or a gasoline engine. The speed of pulling should be uniform and fairly high, as the friction against the walls of the duct is then less than at slow speed. The reel should be prevented from revolving too rapidly.

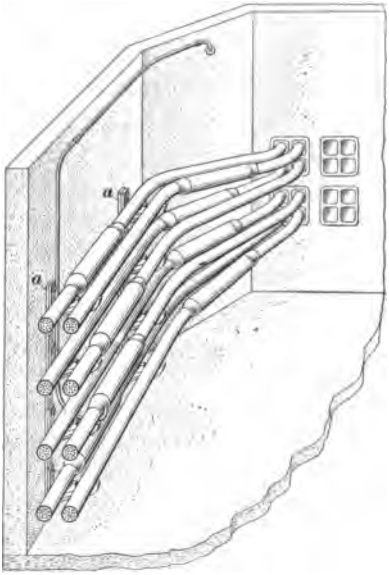


FIG. 113

When the cable has been pulled from one manhole to the next, it is cut off so as to leave about 10 feet of slack in each manhole and is fastened up temporarily against the wall of the manhole. The reel is then moved to the next manhole and the process of pulling is repeated. The splicer later on removes the surplus cable from the manholes after completing his work.

76. The arrangement of cables in a manhole is very important. Each cable should be readily accessible, as indicated in Fig. 113, which shows the usual arrangement. Upright iron frames *a* attached to the wall contain notches for receiving the brackets that support the cables. The splices are staggered so that they do not interfere with one another.

The method of withdrawing cable is much the same as that of pulling it in. The cable is reeled if fit for use elsewhere; otherwise, it is cut into short lengths and sold as junk.

PLACING LATERAL CABLES

77. The branch cables used for connecting aerial or block cable to the underground cable in the subway usually do not exceed 150 or 200 feet in length. The lateral is threaded with a steel fish wire while being laid, and this wire is used to pull in the drawing rope. The exact length of the cable necessary to reach from the manhole to the top of the pole is predetermined by measurement, and about 20 feet additional length is allowed to provide slack for splicing. Because of the great care necessary to guard against injury to the cable in rounding the turn at the riser pipe, the pulling is usually done by hand with the aid of a block and tackle. About 15 feet of the slack is left in the manhole, clamped temporarily to the wall, and 5 feet is coiled and hung on the pole near the terminal box. If the lateral is unusually long or contains bends around which cable cannot be readily drawn, a *service box*, or small manhole, is provided between the pole and the subway. This provision can sometimes be avoided by removing several sections of the lateral near the base of the pole, pulling the cable to this point, threading it through the riser, and then replacing the removed sections with split tubing.

CROSS-CONNECTION BOXES

78. Underground cables range in size from 100 to 600 pair, from one to four branches, depending on local requirements, are usually taken out at each manhole. In order to economize conductors in an underground cable, each pair is usually connected through laterals with several different cross-connection boxes on poles. Fig. 114 indicates the usual method, each line in the diagram representing a pair of wires. Each pair in the cable can thereby be connected with any aerial pair or with more than one such pair by means of short pieces of wire called *jumper wires*, or *cross-connection* wires, *a*, in the boxes. The illustration shows only four pair in a cable, each pair connected with three cross-connection boxes *A*, *B*, and *C*. Cable pair No. 1 is in use through box *A*, No. 2 through box *B*, No. 3 through box *C*, and No. 4 through all three boxes for party-line service. Such a diagram showing the complete lay-out of a cable is given to the splicer to guide him in his work.

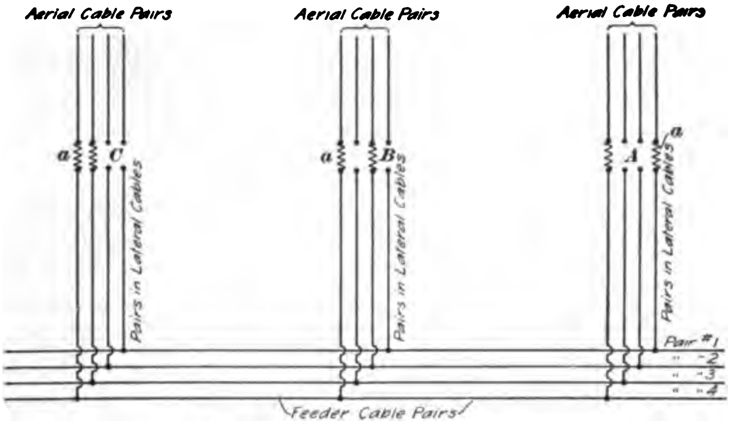


FIG. 114

TESTING AND SPLICING UNDERGROUND CABLE

79. The splicer should first ascertain that sufficient slack has been left in each manhole and, if possible, should pull the cable to correct a deficiency in any manhole. He should then *set up* the cable in the manhole in which his first work is to be done by bending it from the duct toward the wall, allowing a straight run of at least 4 inches from the duct opening.

In bending, care should be taken not to pinch or buckle the cable; if necessary, a dresser, or small wooden tool, of the special form shown in Fig. 115 should be used, care being taken not to hammer the cable hard enough to endanger the sheath. Bending the cable will be facilitated by opening the end, thus allowing the wires more play. Cables should be placed on the manhole walls in a position corresponding to the duct from which they are taken. In so doing, care should be exercised not to run the cable across others already in the manhole, or to run it across the opening in any of the unused ducts.

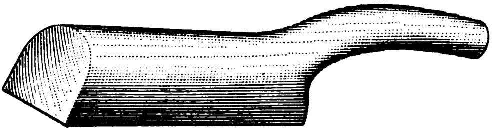


Fig. 115

80. The insulation is stripped from the ends of the wires, which for convenience in splicing are then bound in bundles of 100 pair each, as shown in Fig. 116. The splicers begin work in the manhole nearest the central office and splice the wires of each bundle to those of a bundle in the next section of the cable, until a manhole is reached where the cable branches or changes in size; this method is known as **random splicing,** no attempt being made to select wires to splice together.

81. If the cable branches or its size changes in a manhole, the splicer must keep in communication with a helper at the main frame in the central office. The splicer is equipped with a test set consisting of a head receiver strapped in place, a small transmitter arranged to hang where he can readily speak into it, a buzzer relay, and a pair of batteries. He is also provided with a **test board,** shown in Fig. 116, for differentiating the various pairs in a bundle. This device consists of a rectangular perforated board with numbered holes, each large enough to permit the insertion of one pair. The helper is provided with a test set consisting of a receiver and a transmitter which he bridges across a pair of wires in the cable to be spliced, at the same time grounding the ring side of the pair. The splicer grounds one terminal of his test set and runs the other over the exposed ends of the wires until his relay responds and thus

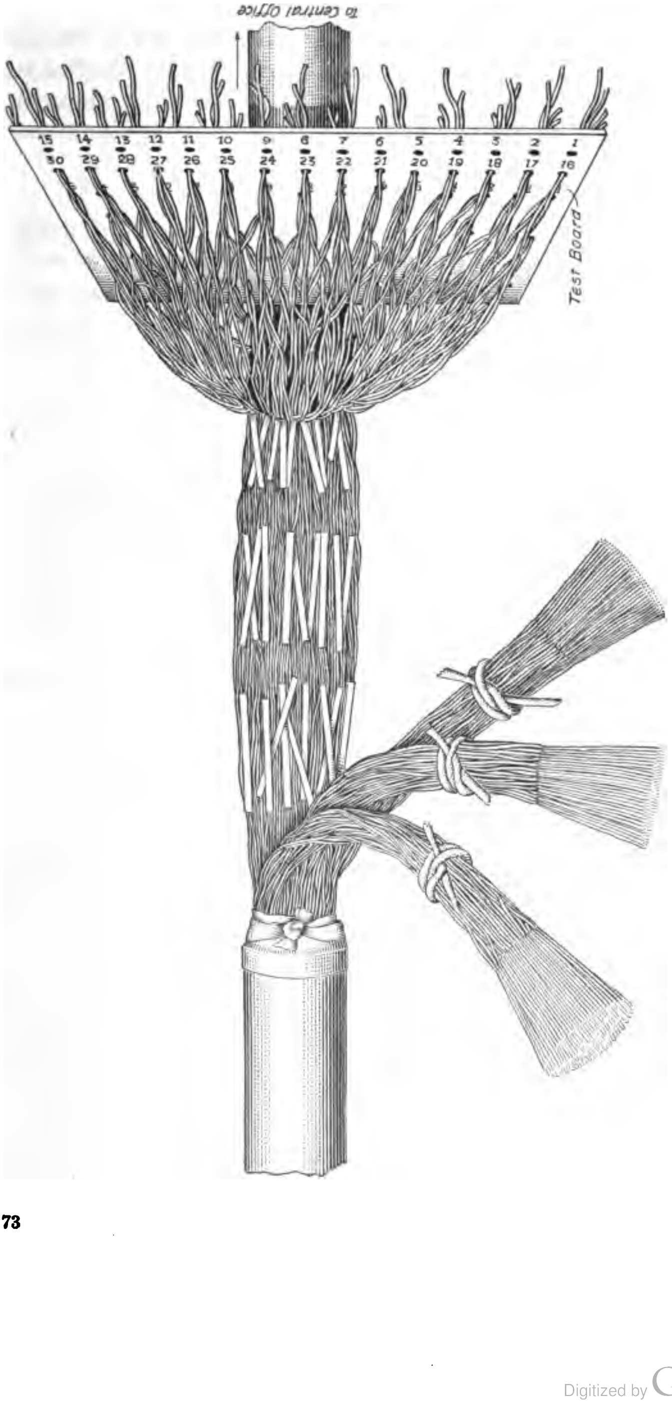

To Central Office
Test Board

Fig. 116

locates the pair across which the helper's set is connected. The splicer then connects his set across this pair, which is thereafter used as a talking circuit. The helper then connects one side of his test set through a condenser to the ground and the other to a test point.

82. If pairs Nos. 1 to 100, for example, are required for a branch, the splicer connects his test point with the end of a pair, selecting pair No. 1 as nearly as he can judge, and the helper runs his test point over the terminals until he touches the other end of the same pair, as indicated by a click in his receiver, when he calls the number of the pair to the splicer. This pair is then fed through the hole in the test board bearing the proper number. An experienced splicer can usually find pair No. 1 after two or three trials, and the remaining pairs for the branch are similarly identified, one by one, and placed in the test board. The helper then goes to the box in which the branch terminates and helps to identify the pairs of the branch. When the splicer has all the pairs identified, he splices the branch wires to those selected from the main cable as previously described for aerial cable splices, except that special care must be taken to prevent the wires from becoming moist. A sheet of canvas is often placed over a splice to guard it from moisture dripping from the manhole roof. A splice left unfinished during the night or over Sunday should be temporarily wrapped with adhesive tape or oilcloth to insure protection from moisture. When work is resumed, the splice should be thoroughly boiled out, or treated with hot paraffin, before completing the operation of splicing, in addition to the boiling at the beginning and at the end of the process.

By a comparatively new method of taking off a branch, a short stub cable is spliced to the underground cable and the branch is spliced to the end of this stub. By this means the necessity for opening the splice in the main cable is avoided.

MAINTENANCE AND ORGANIZATION

PLANT MAINTENANCE

NECESSITY FOR INSPECTIONS AND TESTS

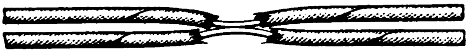
1. In addition to the inspections and tests already described in connection with the maintenance of subscribers' equipments, a complete testing system is essential, not only to find and correct faults that occur after the system has been in use, but also to correct mistakes that may be made while installing the system. Fig. 1 shows some of the faults and mistakes that may be found.

2. Opens, shorts, crosses, and grounds may be of varying degrees, the word *dead* being used to indicate the worst degree, as a dead open, dead short, etc. The troubles may also be intermittent, such as caused by bare wires swinging together in the wind. Intermittent troubles are sometimes so elusive and hard to find that they are called *phantom troubles*.

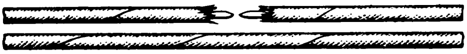
3. **Foreign, or extraneous, currents** may be set up in telephone circuits either by conduction or by induction. In either case such currents not only cause disagreeable noises, but they may overheat conductors and possibly cause fires. Good insulation and the proper separation of wires is the remedy for leakage currents, or those entering the telephone circuits by conduction, and proper balancing, or twisting, of conductors prevents inductive currents.

COPYRIGHTED BY INTERNATIONAL TEXTBOOK COMPANY. ALL RIGHTS RESERVED

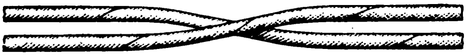
4. Among the mistakes sometimes made when installing conductors are *reversed pair*, *split pairs*, and *transposed pairs*. When the conductors of a twisted pair are interchanged, a **reversed pair** is formed; for example, the tip and ring strands may be interchanged, the battery or the generator may be connected with the wrong polarity, a party line may be connected so as to cause wrong signals, etc. If individual wires of two or more pairs are interchanged, **split pairs** are formed. This mistake is most likely to be made when several pairs follow a parallel route. It is particularly hard to find, because the circuits may be complete and without shorts, grounds, or crosses. **Transposed pairs** are caused when both wires of a pair are interchanged with those of another pair, so that neither pair terminates where intended.



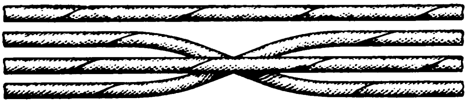
Short-Circuited Pair



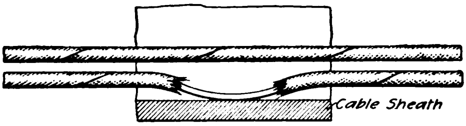
Open Pair



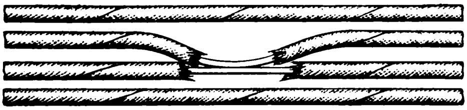
Reversed Pair



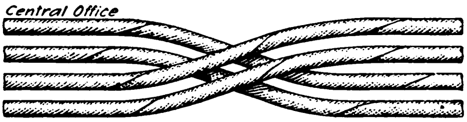
Split Pairs



Grounded Pair



Crossed Pairs



Transposed Pairs

FIG. 1

TESTING AND MEASURING INSTRUMENTS

5. A telephone receiver is not only a very effective testing instrument but it also affords a means of communication between workmen at a distance from each other, provided they are connected by a suitable circuit. An ordinary hand receiver can be used, but a head receiver is better, as both hands are then free. For common-battery work a receiver and a transmitter attached to the same handle and connected together in series are often employed.

LINEMAN'S TEST SET

6. A common form of **lineman's test set,** shown in Fig. 2, is adapted for use on local-battery and common-battery lines. The box contains a transmitter of the solid-back type mounted just inside of a perforated plate that serves as a mouthpiece. The receiver is of the watch-case type, held on the outside of the box by clamping springs. The box contains a buzzer, a two-bar generator, dry cells, and a suitable induction coil. The generator handle is on the opposite side of the box from the receiver. The dry cells are for energizing the local circuit of the transmitter; this circuit is closed only when the push button on the front of the cover is pressed. The knurled knob on top of the box moves an interior switch, which controls the talking and ringing circuits, enabling the various combinations to be made as required.

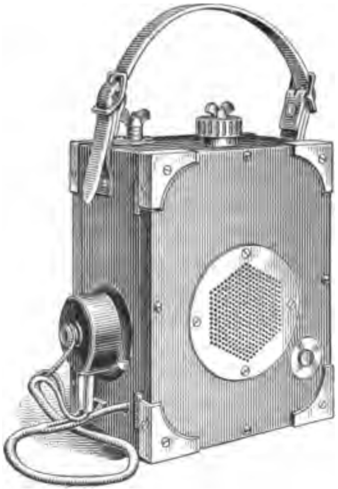


FIG. 2

7. In the majority of small telephone exchanges of tne magneto type such a set constitutes the entire testing equipment. By means of it, the lineman can perform a variety of tests that could not be made with the receiver alone. It is virtually a complete magneto telephone set in portable form, and by connecting it to a line the workman can call up and communicate with the central office to report or to receive instructions.

THE WHEATSTONE BRIDGE

8. The **Wheatstone bridge** is an instrument that is much used for measuring resistances. Its general theory may be explained by reference to Fig. 3, in which a divided circuit is represented between two points *a* and *b*. As the drop of potential in each of the two paths *a c b* and *a d b* is the same, any point *c* in one of the paths has a corresponding point *d* in the other at exactly the same potential; if a conductor is connected to one path at *c* and the other end of the conductor is moved along the other path, no electricity will flow in this conductor when the point *d* is found. Then the drop of potential from *a* to *c* must be the same as from *a* to *d*, and the drop from *c* to *b* must be the same as from *d* to *b*. That is, voltage drop $a\,c = a\,d$, and $c\,b = d\,b$. By dividing the first equation by the second, $\frac{a\,c}{c\,b} = \frac{a\,d}{d\,b}$. This may be called the equation of the Wheatstone bridge. It is often written as a proportion, thus

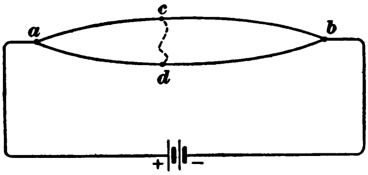


FIG. 3

$$a\,c : c\,b = a\,d : d\,b$$

As the voltage drops in each part of the bridge that is carrying the same current are directly proportional to the resistance of the part, the letters of the proportion may represent either voltage drops or resistances.

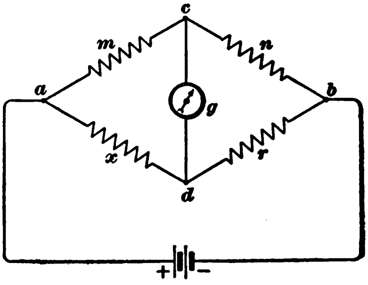


FIG. 4

9. In Fig. 4 the same two main branches are indicated, each consisting of two resistances in series; the points *c* and *d* are connected by a galvanometer *g*. When the four resistances are properly balanced so that the points *c* and *d* are at the same potential, the galvanometer needle will show no deflection, and the four resistances will have the relation $\frac{m}{n}=\frac{x}{r}$, or $x=\frac{m}{n}r$.

In some bridges the battery is connected between *c* and *d* and the galvanometer between *a* and *b*. The principle of operation of the bridge remains the same, however.

The Wheatstone bridge consists essentially of four arms and a galvanometer connected as in Fig. 4. Three of the arms contain known resistances, some or all of which can be adjusted. The fourth arm is the unknown resistance to be measured. The equation just given, $x=\frac{m}{n}r$, is always true when the known resistances are adjusted to obtain a perfect balance, in which condition there is no current in the galvanometer.

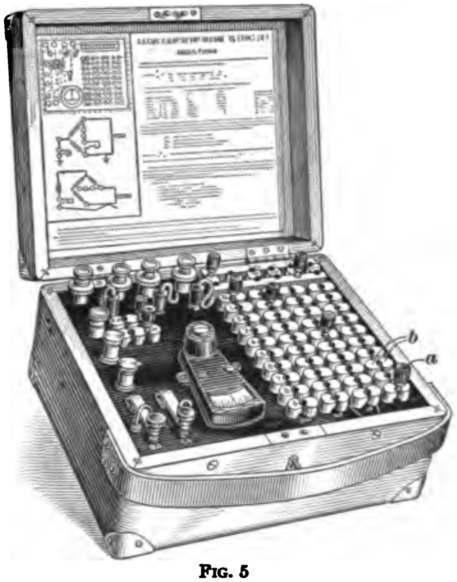


FIG. 5

If $m=100$ ohms, $n=1{,}000$ ohms, and $r=990$ ohms when the bridge is balanced, then

$$x=\frac{100}{1{,}000}\times 990=99 \text{ ohms}$$

10. The adjustable resistances, or **rheostats**, in a Wheatstone bridge may be of the dial type, adjusted by turning a knob, or of the plug type, as shown in Fig. 5, adjusted by inserting metal plugs *a* between metal blocks *b* that form terminals of the sections of resistance. In all cases, two of the arms, called *ratio arms*, can be adjusted so that only a decimal ratio can be obtained between their resistances, as 1 to 10, 1 to 100, 1 to 1,000, etc. An approximate balance is obtained by adjusting the ratio arms, and an accurate balance by then adjusting the remaining rheostat arm. The product of the resistance in this arm and the ratio between the resistances in the ratio arms is then the resistance being measured.

GALVANOMETERS

11. The indicating action of all galvanometers depends on the electromagnetic action between the current being indicated and a magnetic field. Sometimes the magnetic field is that of the earth, which always tends to hold the needle in a north-and-south position, and sometimes it is that of a powerful permanent magnet. Sometimes the needle is itself magnetized; in other cases the coil of wire that carries the current to be measured is the movable element, and virtually constitutes the needle. No matter which of these arrangements is used, the extent of the needle deflection that a given current will produce is used to determine the amount of that current.

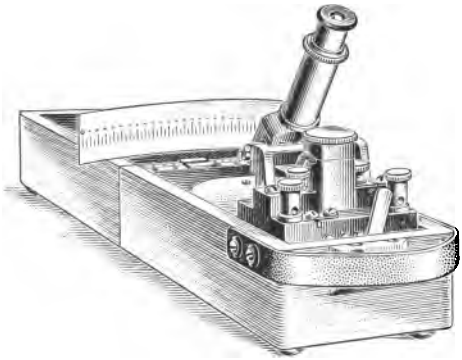


FIG. 6

12. In some cases the needle carries a pointer that moves over a scale, so that the deflection can be directly read. In other and more delicate instruments, the needle or coil carries a very small mirror. The deflection can then be measured by watching a spot of light that is reflected from the mirror to a scale, or by observing the mirror through a telescope so arranged as to receive the reflection from a stationary scale. Such galvanometers are called reflecting galvanometers. One of these, with its telescope and scale arranged for portable use, is shown in Fig. 6 The principle employed in reading the deflection of the reflecting galvanometer needle by means of the telescope and scale is shown in Fig. 7. In this case the pointer is a beam of light, and a very long pointer can be secured without adding any weight to the movable coil of the galvanometer. The object of a long pointer is to obtain more delicate readings. The purpose of the stationary mirror in Fig. 7 is merely to get a sufficiently long beam of reflected light without taking up much space in the instrument.

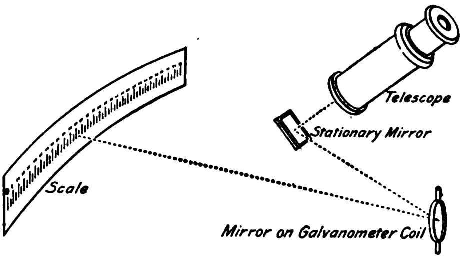


FIG. 7

VOLTMETERS AND AMMETERS

13. The modern voltmeter and ammeter are essentially alike in that each is a form of galvanometer, the deflection of which is read directly by a pointer. In these instruments the markings on the scale over which the pointer moves are so graduated as to read directly in volts or in amperes, according to whether the instrument is a voltmeter or an ammeter. In a voltmeter, the resistance of the circuit through

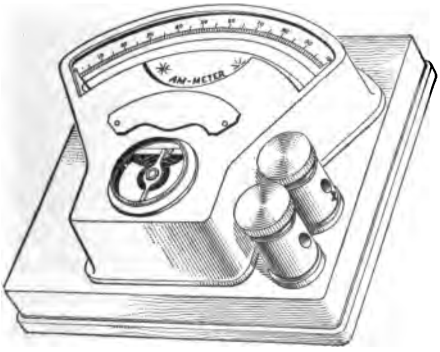


FIG. 8

the coil is very high so that the current in the coil is small. Although the instrument is in reality a current-measuring instrument, the current is proportional to the voltage, which is marked on the scale so as to make the instrument read directly in volts. In an ammeter, the resistance of the coil is very low, so that the drop of potential through it will be negligible. Its scale is so marked as to read directly in amperes.

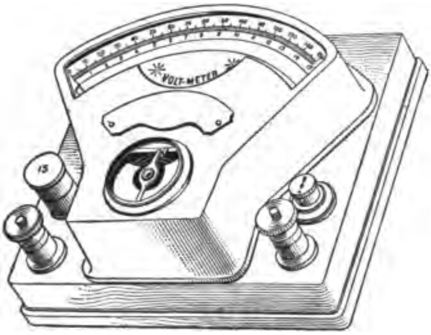


FIG. 9

14. Beginners must remember that the proper way to connect a voltmeter is *across the circuit* of which the voltage is to be measured, and an ammeter should be connected *in series with the circuit* in which current is to be measured. An ammeter should never be connected across a circuit unless enough resistance is used in series to keep the current within the range of the instrument. In no case should either a voltmeter or an ammeter be connected in a circuit beyond its range; for example, a voltmeter adapted to register only 15 volts must not be connected across a 115-volt circuit.

15. Ammeters and voltmeters are made in both portable and stationary types. Those used in telephone central offices are mostly of the stationary, or switchboard, type. Fig. 8 shows a well-known portable ammeter, Fig. 9 a portable voltmeter, and Fig. 10 a stationary voltmeter.

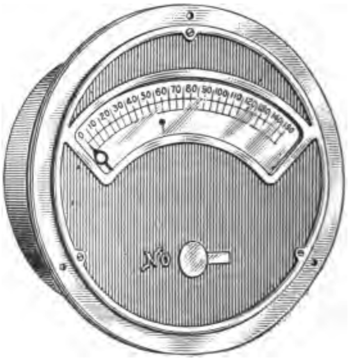


FIG. 10

16. One important distinction between the ordinary portable voltmeter and the special type of switchboard voltmeter usually employed for telephone work is that the portable voltmeter is *dead beat*, or *aperiodic*, and the switchboard voltmeter is *non-aperiodic*, or *ballistic*. In a dead-beat, or aperiodic, instrument the needle comes to rest promptly without a series of vibrations, and the needle of a ballistic instrument swings freely for a brief interval before coming to rest.

CABLE-TESTING SETS

17. A cable-testing set is merely a combination of standard testing instruments, a battery, a resistance, and a condenser, arranged in a compact and portable form. However complicated such a set may appear on first sight, the complications will usually disappear when the circuits are studied, and the set will be found to consist of the instruments named, each arranged for connection in the proper way.

18. A combination consisting of an induction coil, a telephone receiver, a battery, and a vibrating circuit interrupter is frequently of service in locating shorts, crosses, and grounds in telephone cables. The general name *fault finder* is given to such sets, though they are sold under various trade names. A coil of the set is arranged to apply to the cable sheath and is known as an *exploring coil.*

If a short is known to exist on a pair of wires in a cable, the battery and interrupter are connected across that pair, and pulsating current is thus set up in both wires of the pair to the short; the short prevents the establishment of current in the wires beyond it. The tester then goes along the cable, applying the exploring coil to the sheath at various points. If he hears a buzz, he knows that the short is farther on; if he does not, he knows that he has passed it. In this way he sometimes is enabled to locate a fault accurately, so that the cable sheath can be opened at the exact point without further trial. Fault finders that depend on the use of exploring coils are of no value in locating opens, because current cannot be set up in an open circuit.

WIRE CHIEF'S TESTING EQUIPMENT

19. All work connected with maintaining a good electrical condition in the lines and equipment is under the direction of a wire chief. A large number of tests are necessary in order to keep well informed concerning this condition. In all except the smallest telephone exchanges, desks for wire chiefs are installed and at each desk is assembled all the necessary testing equipment, including measuring instruments, a source of current, keys, and other switching devices to effect any combination of circuits that may be desired. Trunk circuits lead from the desk to the switchboard so that any line can be extended to the desk for test. Other trunks leading from the desk to the main distributing frame provide means for testing either the outside lines or the inside lines. Fig. 11 shows a typical wire chief's desk of the two-position type, that is, with working space for two test men.

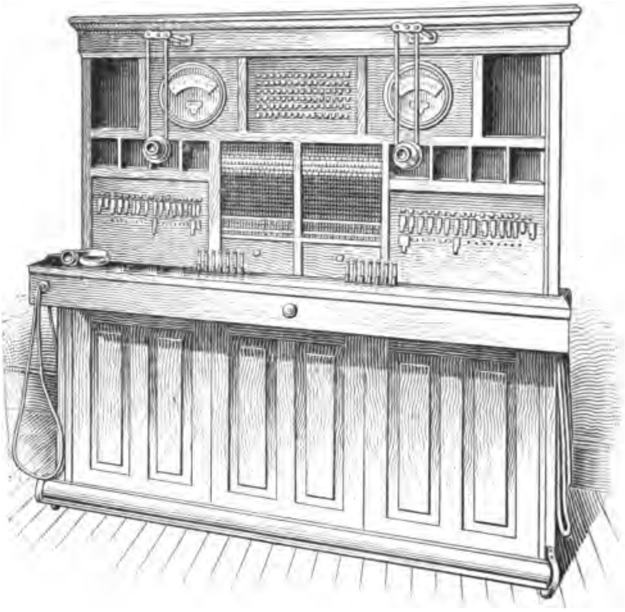


FIG. 11

20. A simpler form of testing equipment largely used in smaller exchanges is shown in Fig. 12. This is in the form of a small cabinet adapted to be mounted in any convenient manner. In the upper part of this cabinet is mounted a voltmeter having a 30-volt scale. Below the voltmeter is a row of keys for performing various switching operations. At the left-hand lower part of the cabinet is a pair of jacks for receiving the operator's plug, so that the regular operator's transmitter and receiver can be connected with the apparatus for carrying out the tests. The two binding posts *A* and *B* at the bottom of the cabinet are for connecting a Wheatstone bridge, and the crank near the lower right-hand corner is to turn a hand generator for signaling.

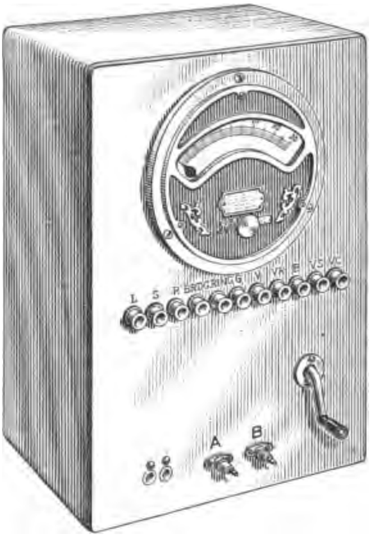


FIG. 12

21. The circuits of a wire chief's equipment nearly like that illustrated in Fig. 12 are shown in Fig. 13, which is also fairly typical of the circuits of a more complete wire chief's desk. The principles involved are the same in all sizes, but the larger and more complete equipment contains some refinements not to be found in this smaller type.

In Fig. 13, the *switchboard test plug* and the *ground plug*, shown at the right, are a pair of ordinary plugs located at some position on the switchboard where they can be used for connecting with any line that it is desired to test. The test plug is adapted to make connection between the tip and ring sides of the line and the several keys of the testing set. The ground plug serves merely to put a dead ground on the tip of the line. These plugs may be formed from a pair of ordinary plugs and cords on a switchboard, the tip and ring of the upper one being wired to the test cabinet keys as shown, and the tip of the lower

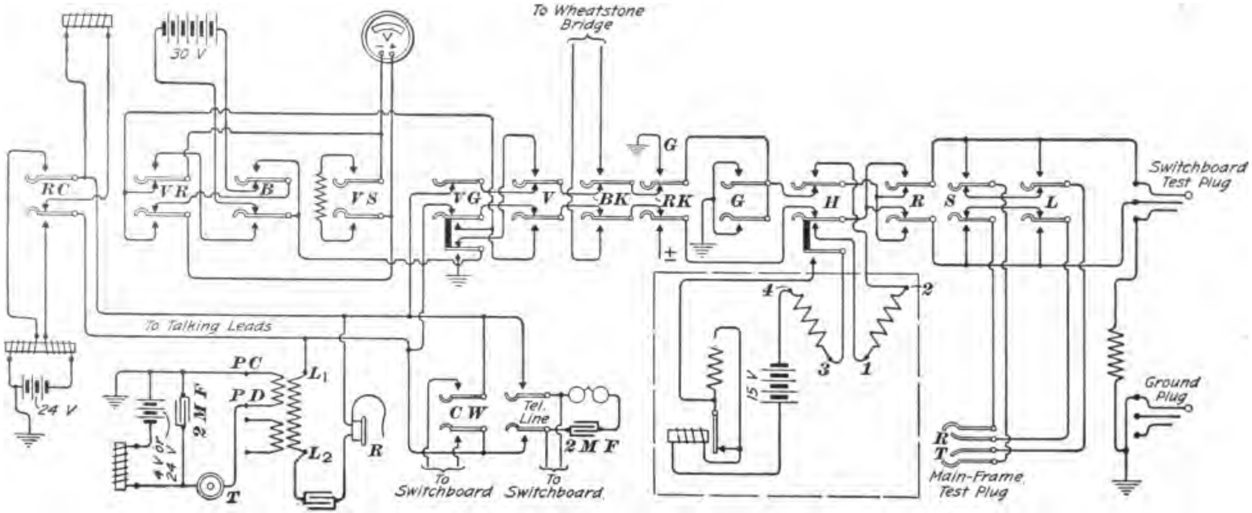

To Wheatstone Bridge
30 V
V
RC
VR
B
VS
VG
V
BK
G
RK
±
G
H
R
S
L
Switchboard Test Plug
To Talking Leads
24 V
PC
PD
L1
L2
2 M F
4 V or 24 V
T
R
C W
Tel. Line
2 M F
To Switchboard
To Switchboard
4
3
1
2
15 V
Ground Plug
R
T
Main-Frame Test Plug

FIG. 13

one being dead-grounded. The sleeve of the upper plug is connected to ground through a 210-ohm resistance, so as to pull up the cut-off relay of the line under test when a plug is inserted.

22. The main-frame test plug is adapted for inserting between the arrester springs of any line on the main frame. Two of the contacts of this plug are then connected with the outside line and the other two with the inside line. By pressing the key *L* (line) the outside line can be connected for test, and by means of the key *S* (switchboard) the inside line can be likewise connected. The switchboard test plug thus affords a means of connecting a complete line for test, and the main-frame test plug permits a line to be divided at the main frame. The key *R* (reverse) serves merely to reverse the tip and ring sides of the line with the tip and ring conductors of the test set.

23. The next key *H* (howler) is for bringing into action an interrupter and an induction coil so as to set up in the line a high-frequency alternating current. This current will cause any receiver that has been left off the hook to emit a loud noise resembling a howl, which will call attention to the neglect, hence the name *howler*. The interrupter operates on the same principle as an ordinary vibrating electric bell except that instead of entirely opening the primary circuit, a high resistance is alternately cut into and out of circuit by the armature of the vibrator magnet.

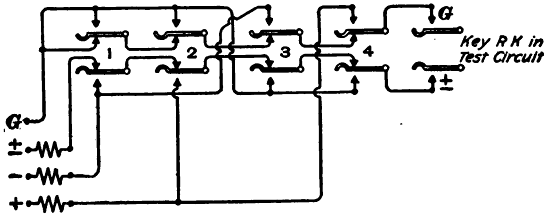


FIG. 14

24. The key *G* (ground) serves normally to ground the tip side of the test circuit, but by throwing the reversing key can be used to ground the ring side. The key *RK* (ringing key) serves to connect the ringing generator across the test leads.

The arrangement shown is that for a single alternating-current ringing machine having one side grounded. If the set is to be used in systems employing four-party selective ringing, the two leads marked *G* and ± of this ringing key are connected with another set of four keys, as shown in Fig. 14. With this arrangement the wire chief can establish in any line under test the proper ringing current for ringing any station, thus cooperating with the inspector at the station in securing the proper adjustment of his bell.

25. The key *B K* (bridge key), Fig. 13, is merely for connecting a Wheatstone bridge across the testing leads. The wires leading to this key are connected across the X terminals of the bridge, so that they and what is included in their circuit become the resistance to be measured. Tests with the bridge are usually made through the main-frame test plug rather than through the switchboard test plug.

26. All of the keys to the left of the bridge key *B K* in Fig. 13, with the exception of the one marked *R C*, are associated with the voltmeter. This voltmeter has an internal resistance of 10,000 ohms. When the key *V* is thrown, all of the others remaining normal, the voltmeter is connected in series with the 30-volt battery across the circuit of the line. This is an important test, since it places the voltmeter, the battery, and the circuit of the line in series. The deflection of the voltmeter will be a rough indication of the total resistance of the line; that is, the deflection will be approximately according to the conductivity of the circuit, and will range between zero deflection with an open circuit and the full 30-volt deflection with a dead short circuit at the switchboard. In fact, an excellent way to test the battery voltage is to plug into an idle jack short-circuited for this purpose.

When the test plug is in a line jack and all subscribers' instruments are disconnected, so as to leave the line open, pressing the voltmeter key *V* will connect the voltmeter and battery in series with the line insulation, and the only deflection will be that caused by current leakage. The poorer the insulation of the line, the greater will be the deflection. A rough idea of line insulation can thus be obtained from the extent of the deflection.

27. A rough measurement of the capacity of a line can be obtained by opening it at its outer end and throwing the voltmeter key *V*. There will be a rush of current into the line to charge it, and this rush will cause a momentary throw of the voltmeter needle, which will be large if the capacity of the line is high and small if the capacity of the line is low. A more reliable test on a metallic circuit is made by closing the voltmeter key and then operating the reversing key, thus doubling the effect of the line capacity on the throw of the needle. The momentary throw of the needle, indicating the line capacity, must be distinguished from its final position indicating leakage current.

28. The key *VG* (voltmeter ground), Fig. 13, serves to connect the voltmeter in series with the battery between one side of the test leads and ground, simultaneously opening the other side. By means of the reversing key *R*, either side of the line can be so connected and its insulation to ground thus measured. By means of the key *VS* (voltmeter shunt), a 200-ohm resistance coil can be connected directly across the voltmeter terminals, thus increasing the sensitiveness of the instrument for measuring low resistances.

29. The key *B* (battery) serves to cut off the battery from the testing leads. With the key *B* and the key *V* thrown, the voltmeter is bridged directly across the testing leads without the battery. One purpose of key *B* is to permit of measuring any difference of potential across the line or between either side of the line and ground, such as might be due to extraneous currents. The key *VR* (voltmeter reverse) serves merely to reverse the normal connection of the voltmeter with the testing leads, which may be necessary in order to indicate voltage on the lines when their polarity is reversed. The key *RC* (retardation coil) forms no part of the testing combination. Its functions relate wholly to the circuits by which the wire chief may talk over the lines.

30. The wire chief's transmitter *T* and receiver *R* terminate in a plug and are connected with the testing cabinet by means of the pair of operator's telephone jacks, shown in the lower left-hand corner of the cabinet in Fig. 12. The wire chief's talking set is bridged across the talking leads that terminate at the left in the key *R C*, Fig. 13. With this key in its normal position, a 500-ohm retardation coil is bridged across the talking leads. When the key is thrown into its alternate position, this retardation coil is cut out and a 24-volt battery, with two 85-ohm retardation coils, is bridged across the talking leads. These talking leads are normally connected across the testing leads at key *V G*, and unless the testing leads are opened by some key to the right of *V G*, the wire chief can talk with any one on the line with which the test plug is connected. Throwing the voltmeter key *V* disconnects the talking circuit from the test circuit. Both the voltmeter and the talking circuit cannot therefore be connected with the test circuit simultaneously.

31. The key *C W* (circuit-wire key), shown at the right of the telephone set, is for the purpose of connecting the wire chief's telephone set to the telephone set of the operator at the switchboard position in which the switchboard testing plug and grounding plugs are located. This arrangement, although not always employed, greatly assists the wire chief in ordering up the lines for test. At the right of the key marked *C W* is shown a telephone line key, which is connected with a 2-microfarad condenser, a 1,000-ohm bell, and a line to the switchboard. By throwing the telephone line key, the wire chief connects his talking set so that he can be called from any part of the system.

METHODS OF TESTING

DETERMINATION OF FAULTS

32. Most of the tests made with a wire chief's equipment are made to determine what faults exist. Such tests can usually be made with the voltmeter as the only measuring instrument and may therefore be called *voltmeter tests*. In the following discussion, the keys are referred to as in Fig. 13. The line to be tested is first connected with the wire chief's equipment, after which its condition can be revealed by voltmeter tests.

33. To test for continuity of a metallic line, the voltmeter key *V* is operated. A deflection of the needle indicates a continuous line, or possibly leakage current in an open line; no deflection indicates an open line.

To test the continuity of a grounded wire connected with the ring of the jack, the key *VG* is operated, and if the grounded wire is connected with the tip of the jack the key *R* is also used. In either case a deflection indicates continuity of circuit to some ground on the line, possibly a fault and possibly a normal ground through the apparatus. If condensers are used in series with the ringers between the line and the ground, as is the case with common-battery sets, no permanent deflection will occur. In this case a continuity test can be made by operating the battery key *B* several times, causing momentary deflections owing to the charge and discharge of the condensers.

34. A test for a short circuit can also be made by operating the voltmeter key *V*. A deflection very near the full battery voltage indicates a short circuit not far from the testing equipment; a somewhat smaller deflection indicates a short circuit farther away.

The line resistance can be found by the formula,

$$R_l = \frac{(E-e)\, R_v}{e}$$

in which R_l = line resistance, in ohms;
E = full battery voltage;
e = deflection of voltmeter needle;
R_v = resistance of voltmeter, in ohms.

For example, if a 25-volt deflection is obtained with a 30-volt battery and the voltmeter resistance is 10,000 ohms, the resistance of the line is

$$R_l = \frac{(30-25)\times 10{,}000}{25} = 2{,}000 \text{ ohms}$$

More accurate calculations of line resistances that are comparatively low can be made by also operating the key *VS*, placing 200 ohms in shunt with the 10,000 ohms of the voltmeter and making their combined resistance 196 ohms $\left(\frac{1}{\frac{1}{200}+\frac{1}{10000}}=196\right)$. A 10-volt deflection with a 30-volt test battery then indicates a line resistance of $\frac{30-10}{10}\times 196$ $=392$ ohms. By thus measuring the resistance of a line, distinction can be drawn between a short-circuited line and a line having one or more bridged bells without condensers.

35. The **test for a ground** is the same as for the continuity of a grounded line. For the ring side of the line, operate the key *V G* alone, and for the tip side of the line operate both keys *V G* and *R*. The voltmeter should show no deflection, or at most a small one, if the line is clear, except in the case of grounded lines and party lines on which the bells are rung with a ground return without condensers in series with the ringers. The resistance in this case may be measured as in the case of short circuits.

36. **Tests for crosses with lines carrying current,** such as telegraph lines or common-battery lines, are made in the same manner as tests for grounds, except that key *B* is operated as well as *V G* and *R*. If the needle moves backwards when key *B* is operated, operate key *V R*, which will reverse the voltmeter connections so as to make the reading appear on the voltmeter in the right direction. Great care should be used in making this test for a cross with a line carrying an unknown voltage, as there is danger of injuring the voltmeter if the potential of the foreign line is much in excess of 30 volts. It is always well to begin such tests with the key *V S* thrown so as to shunt the voltmeter and thus guard it from injury.

37. **To test for a cross between two telephone lines,** first ascertain that both of the lines are free from grounds. Then ground one of them by plugging into it with the ground plug shown at the right in Fig. 13. Then test the other line for grounds as already explained.

38. A **ballistic test** may be used for roughly determining the capacity between the tip and ring sides of the line. Operate the key *V* and then operate key *B* several times in succession, noting the throw of the voltmeter needle. The greater the throw, the greater is the capacity between the two sides of the line. If the voltmeter is not shunted, the capacity is proportional to the deflection. To measure the capacity between the ring side of the line and ground, proceed in a similar manner, but use the keys *V G* and *B*. To measure the capacity between the tip side of the line and ground, use keys *VG*, *R*, and *B*.

This ballistic test may be used for locating the distance to a break by comparing the capacity of the line with its normal capacity, which has previously been determined and recorded. In making these tests on metallic lines, key *R* may be used to advantage instead of *B* for charging and discharging the line. On operating and restoring key *B*, the voltmeter deflections are in opposite directions, while with key *R* they are always in the same direction and of twice the magnitude. Key *R*, however, cannot be used in this way for measuring the capacity between one side of the line and ground.

LOCATION OF FAULTS

39. Murray and Varley Loop Tests.—After the existence of faults has been determined by means of the voltmeter

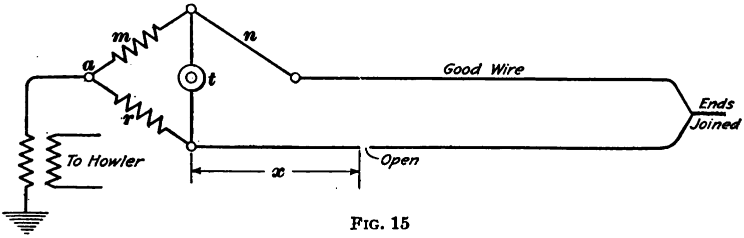


FIG. 15

tests, the faults can often be located with a fair degree of accuracy by some modified form of the Wheatstone bridge test. Fig. 15 shows the connections for **locating an open** by the

Murray loop test. The distant ends of the circuit in which the open exists are joined electrically, and the ends in the office are connected with two bridge terminals, as indicated. A telephone receiver is connected in place of the usual galvanometer and a source of alternating current, such as the howler, Fig. 13, is connected between the point a, Fig. 15, of the bridge and the ground. The resistance of the arm n is short-circuited and the resistances of arms m and r are adjusted until no noise can be heard in the receiver. The bridge is then balanced, and the distance in feet to the fault may be found from the formula

$$x=\frac{2\,l\,m}{r+m}$$

in which x = shortest distance, in feet, to the fault;
l = length of good wire, in feet;
r and m = resistances, in ohms, in the bridge arms.

For example, if, in testing for an open in a 1,500-foot wire, m is 100 and r 300 when a perfect balance is secured, then $x=\frac{2\times 1{,}500\times 100}{300+100}=750$ feet from the office to the open.

40. The connections for **locating a ground** in a long cable by the Murray loop test are shown in Fig. 16. A battery and key are substituted for the source of alternating current between the point a of the bridge and the ground, and a galvanometer and key are substituted for the telephone receiver in the bridge wire. The grounded circuit is connected in place of one arm of the bridge, as shown, the resistance of the adjacent arm n is short-circuited, and the resistances in the other two arms adjusted until the galvanometer shows no deflection, when

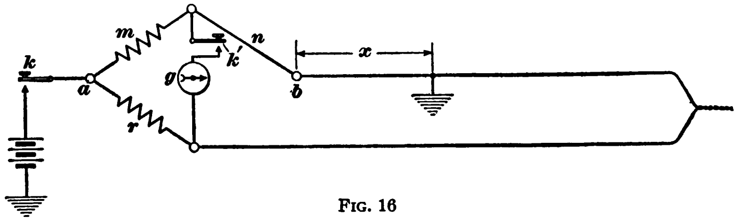


FIG. 16

both keys *k* and *k'* are closed. The system is then balanced and the formula of Art. **39** can be used to find the distance *x* to the ground.

41. In **locating a cross** by the Murray loop test the connections are practically the same as for locating a ground, except that the battery is connected with one of the crossed wires instead of with the ground. In Fig. 17, wires *1* and *2* represent a pair, and wire *3* belonging to another pair is crossed with wire *2* at a point to be located. If wires *1* and *2* are of the same size, the formula of Art. **39** can be used after a balance has been obtained.

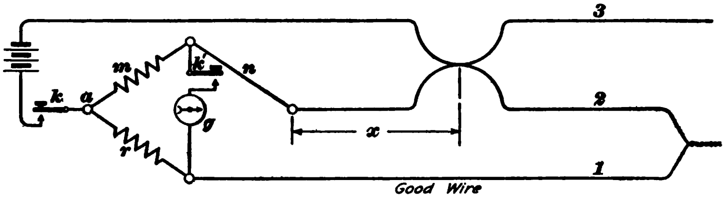


FIG. 17

42. Another bridge test, known as the *Varley loop test*, is frequently used to check values found by the Murray loop test. The connections in the Varley loop test for locating a ground are shown in Fig. 18. The grounded loop is connected at *b* and *c* and forms an arm of the bridge, adjacent to the rheostat arm *r*. The galvanometer circuit containing a key *k'* is connected across the extremities of the ratio arms *m* and *n*, and the battery circuit containing a key *k* is connected between the point *a* where these arms join and the ground. When

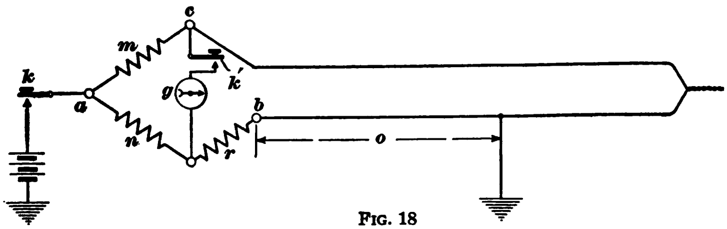


FIG. 18

the resistances are adjusted for a balance, the distance may be found by the formula

$$o=\frac{n\,R-m\,r}{m+n}$$

in which o = resistance of wire to ground;
R = resistance of entire loop, or circuit;
n, m, and r = resistances of bridge arms when system is balanced.

43. The resistance R of the entire circuit can be determined by a Wheatstone bridge test, which can be made by connecting the battery between the points a and b and adjusting the resistances m, n, and r to obtain a balance, after which the bridge formula $R=\frac{m}{n}r$ can be used.

44. By means of these loop tests a skilled operator can locate a fault in a cable within a few feet. But so many of the conditions in the tests are likely to vary and introduce small errors in the results that before opening the cable it should be carefully examined in the supposed vicinity of the fault and possibly tested with an exploring coil.

SWITCHBOARD TESTS

45. The tests so far outlined apply mainly to the outside lines, or, more properly, to the portion of the lines between the main distributing frame and the subscriber's station. These tests are of little value in connection with the inside lines because of the complicated circuits of the switchboard with the various grounds, battery connections, bridges, and contacts necessarily employed.

46. Owing to these complexities, central-office testing requires a clear understanding of all the circuits, their wiring, and the methods of operating them; each test must then be adapted for its particular need. Trouble in a switchboard is usually located by inspection. To the experienced trouble man a failure often suggests its cause or at least suggests the tests necessary to locate the cause. For example, if a line lamp fails to light when a subscriber on a common-battery system removes his receiver from its hook, a test at the main distributing frame will reveal whether the trouble is outside or inside the office. If outside, it may be in the subscriber's hook switch or the line may be open. If the outside line tests clear, showing that the trouble is inside, the line lamp may be burned out or its circuit opened by dust between relay contacts, or the line relay may be defective.

In general, the search for trouble may be assisted by operating the various pieces of apparatus either by hand or electrically and observing the results to see whether the proper functioning of the various associated parts of the circuit follows. A complete set of rules for locating the various switchboard troubles cannot be prescribed, on account of the many types of switchboards and the multitude of troubles that may exist in any one type. A sound idea of the underlying principles involved in the operation of the switchboard and the application of common sense, together with the rules prescribed by the particular company for which he is working, will enable any intelligent repair man to obtain satisfactory results.

ORDER OF CLEARING CENTRAL-OFFICE TROUBLE

47. Some central-office troubles are very much more serious than others; that is, some interfere with service more than others. In clearing troubles, those liable to interfere with the service of the greatest number of subscribers should be found and remedied before an attempt is made to discover and remedy troubles of minor importance. For example, in an exchange served by a one-position switchboard, a fault in the operator's set may disable the entire exchange; a fault in the apparatus of a subscriber's line will interfere with the service of that subscriber only; and a fault in a particular cord circuit may be of little moment, provided there are enough good cord circuits in the position to handle the traffic. Of these three classes of faults, the operator's telephone set should, therefore, be attended to first, the subscriber's line second, and the cord circuit last.

48. In the larger central offices, the force that maintains the equipment is usually divided into a day force and a night force. The duties of the day force are to repair with minimum delay such troubles as interfere immediately with the service. The troubles that do not seriously interfere with the service or operation of the switchboard are not attended to during the busier hours of the day, but are left for the night force to clear. The attempt to clear all trouble during the daytime would, in many cases, interfere seriously with the operation of the switchboard, and there would be delays in handling the calls. The night men also make many routine tests and inspections, the object being to detect and remedy defects and weak places before they have actually developed far enough to interfere with the telephone service.

49. The troubles that develop in the various portions of the central-office equipment should receive attention in approximately the following order: (1) Power-plant trouble affecting entire office; (2) order wire; (3) B, operators' positions; (4) outgoing trunks; (5) incoming trunks; (6) desk circuits essential in conduct of business; (7) A, operators' positions; (8) subscribers' lines; (9) A, operators' cord circuits; (10) desk circuits other than those necessary in the conduct of the business.

The troubles in the different parts of the equipment vary from day to day, and the day force should clear all trouble that has immediate and the most widespread bearing on the service. Frequently this does not take all of the time of the day force; the remaining time can be used to make special inspections of the equipment and clear trouble that might at other times be done by the night force.

USE OF LINEMAN'S TEST SET

50. Small exchanges may rely solely on tests made with a lineman's test set for locating trouble, instead of employing a wire chief's equipment. On being advised that a subscriber cannot be called, for example, and no information being available as to the reason, the trouble man opens the circuit at the main frame, connects his test set to the wires leading to the switchboard, and turns his generator handle.

If the operator responds and they are able to hear each other distinctly in conversation, the trouble man feels assured that the section of the line between the main frame and the switchboard is clear and that the difficulty lies between the main frame and the subscriber. He therefore connects his test set across the line leading to the subscriber and again turns the generator handle. If the crank turns very easily and the buzzer in series with his generator does not respond, he knows that the circuit is open. If, however, his buzzer responds with reasonable loudness, he knows that the circuit is closed. If the generator crank turns very hard and the buzzer responds loudly, he may be fairly certain that the line is short-circuited. A skilled trouble man will be guided, in large measure, by the difficulty with which his generator handle turns. In testing on a long line, a short near the central office will cause the crank to turn harder than if the short is at the remote end of the line.

If these tests do not reveal the nature of the trouble, the generator may be connected in turn between each side of the line and the ground to test the line insulation. If the buzzer makes no response and the handle turns easily, the line is clear. If the buzzer responds and the crank turns hard, the line is grounded.

51. After learning the nature of the trouble, its exact location is largely a matter of inspection. If there is cable in the plant, the trouble man would next go to the end of the cable, open the line there and test in both directions, toward the office and toward the subscriber. By thus advancing from point to point at which the lines can be readily opened the trouble man will finally locate the fault. He may find it at the subscriber's station, possibly in the protector or in the instrument itself. After a little experience the trouble man learns to know where trouble is most likely to be found and he looks in such places first, thus, perhaps, avoiding unnecessary testing.

COMPANY ORGANIZATION

PLANT DEPARTMENT

52. In order to handle the telephone business of a large city successfully, a company must be highly organized. The work must be specialized in departments, each department holding itself responsible for a separate branch of the work. The important divisions are generally the *plant department*, the *traffic department*, the *commercial department*, and the *engineering department.*

53. The **plant department** cares for the maintenance and operation of the plant as a whole. It is in charge of a **plant superintendent** and is subdivided into three departments, a *construction department* under a *superintendent of construction*, an *equipment department* under a *superintendent of equipment*, and a *record department* under a *record clerk.*

CONSTRUCTION DEPARTMENT

54. The construction department incorporates the splicing forces, cable-placing forces, the pole-line gangs, and the forces engaged in the installation of drop and aerial wires. Each subdivision of the department has a *general foreman* in charge, and to him in turn report the *subforemen* in actual charge of the various gangs. As a rule, the construction general foremen are provided with automobiles or motorcycles, so that they can visit the various gangs at least once a day and confer with the subforeman actually in charge of the work. Each subforeman is individually responsible for the satisfactory performance of the work intrusted to his gang and is expected to remain in actual contact with the gang throughout the working day.

55. One or more gangs are detailed to the work of erecting new pole lines, other gangs to the installation of aerial cables, and still others to drop wire and aerial wire work. The members of each gang are generally specialists in their line of work and are usually assigned only to this one line. The gangs used for placing aerial cables, aerial wire, drop wire, pole lines, etc., are usually highly specialized within themselves, each man having his own special work that he attends to regularly unless there is good reason for reassigning the work. To some extent this is also true of the splicing forces, but, as a rule, splicers are competent to handle any branch of cable splicing, and when there is a dearth of underground subway cable work the men are transferred to aerial work, etc. A splicing gang usually consists of two men, a splicer and a helper.

56. Competent foremen study the qualifications of their men, and those men who show ability are allowed to learn the duties of different positions in the gang, promoted to be gang foremen, or transferred on the recommendation of the foremen to other gangs to gain broader experience. Qualifications are thus developed, making men who can fill foremanships and positions of still higher responsibility.

57. The duty of the general foreman is to study the personnel of the gangs under him, maintain general supervision of their work, keep himself thoroughly informed on current construction practice, and act as a sort of information bureau for his subforemen. A good general foreman does not allow himself to become burdened with details, but keeps himself free for general considerations. He or a reliable foreman should be on hand at the beginning of each important piece of work to see that all the men are properly instructed.

EQUIPMENT DEPARTMENT

58. To the superintendent of equipment report the general **foreman of installations**, under whose supervision all new subscribers' equipments are installed, and the **wire chief**, who has charge of the maintenance forces engaged in locating and clearing trouble.

The duties of the general foreman of installation are somewhat similar to the general foreman of the construction department, in that he is expected to keep in active touch with the subforemen who supervise the work of installing subscribers' station equipments. The general foreman is usually provided with a motorcycle, and each morning, after posting himself on the work in hand, visits the various gangs at work and supervises the installation in a general way. Where the territory is large, this is not always possible, and the general foreman may have to devote a large portion of his time to strictly office work and to keeping in touch with his subforemen by means of the telephone. The total number of gangs engaged in installation work is generally larger than that engaged in construction work, but, on the other hand, the gangs do not usually consist of more than two, or at the most three, men except in unusually large installations, such as those of private branch exchanges.

59. Each gang, as a rule, consists of an experienced installer and a helper. The installers are usually competent to meet all of the ordinary contingencies, and are provided with detailed wiring plans and instructions for the installation of the apparatus. Although the installers do not report to the wire chief, they are obliged to secure his approval on completing an installation job. This approval is considered necessary because the wire chief is responsible for the actual working of the line and he should, therefore, test the equipment as soon as the installation is complete. The men engaged in installation and trouble work come more closely in personal contact with the general public than any of the other employes of the telephone company. For this reason it is most important that they shall so conduct themselves as to make favorable impressions on the subscribers. A telephone company is usually a very large corporation, and the public is prone to form an opinion of the corporation as a whole from the conduct of individuals. Courtesy and a willingness to conform with the subscriber's wishes, when this can be done without interfering with the predetermined rules for installation of apparatus, are, then, most important.

60. To the wire chief report the employes engaged in the actual testing of the wires, known as desk men, who operate the equipment of galvanometers, voltmeters, etc. In general, the trouble men and instrument inspectors report directly to the wire chief, but in some instances, where a large territory is involved and a large number of men are engaged in this kind of work, such reports are made to *chief inspectors*, whose duties consist in the actual supervision of the activities of the trouble men. This latter arrangement is usually adopted in large cities, where the diversity of the duties of the wire chief makes impossible his close supervision of instrument maintenance. In addition to his duties in supervising the testing and maintenance of the outside plant and subscribers' station equipment, the wire chief is responsible for the central-office plant, including the routine inspections and switchboard maintenance.

RECORD DEPARTMENT

61. The record department compiles and maintains various plant records, including records of subway locations and duct assignments; records of the disposition of underground feeder, block, and aerial cables; record of the date of installation and condition of each of these cables, as shown by periodic inspection; and the numerous other records necessary to the maintenance of a telephone plant.

62. The cable assignments are generally kept in books or on cards. Cables are numbered consecutively, one set of numbers being used for underground cables, another set for aerial cables, and still another for block cables, so that the number itself will indicate whether the cable in question is underground, aerial, or block. For instance, underground cables may be assigned numbers 1 to 999, aerial cables numbers 1,000 to 9,999, block cables 10,000 to 99,999, etc.

The wire chief is furnished with a duplicate of cable records, as kept by the record department, and in most cases changes of assignment are made at the instance of the wire chief. In the larger cities it is often customary to assign this work to a group of clerks in the record department, and a trouble man in making changes of assignment, in case of defective cable pairs, will call the record department and obtain a new assignment directly, instead of through the wire chief.

63. The record department is also usually required to provide a record of the location and status of the outside plant in general. This record is generally in the form of a map, which shows by a conventional code the location of pole lines, aerial cables, and subway and block cables. In some cases this data is given only in a very superficial way, such as the coloring of the map with one tint to indicate pole lines without cable, another tint to designate pole lines bearing cable, and a third and fourth for subway and block cable, respectively. No attempt is made to show the exact location of poles. These maps are generally used by the record clerks in assigning lines for prospective subscribers. Having the house number, or approximate location of a subscriber's property, the clerk can pick out the cable and terminal most suitably located for the connection of the subscriber in question.

TRAFFIC DEPARTMENT

64. The **traffic department** attends to the manipulation of telephone apparatus used in interconnecting subscribers' lines, and may therefore be called the *operating department*. It is under the general supervision of a **superintendent of traffic.** The operating force of each local exchange is under the direction of a **chief traffic manager,** practically always a man, who has full charge of the force and is held responsible for results. He can hire, promote, reassign, and discharge operators as may seem necessary to obtain efficient and satisfactory service.

65. The principal aid to the traffic manager is a **chief operator,** almost always a woman, who is responsible for the discipline of the operators. She arranges their positions at the switchboard, their hours of work and rest, recommends promotions, dismissals, etc., and attends to the general business of the exchange.

66. Under the chief operator are several **supervisors,** one for every few operators, behind whom the supervisor constantly patrols so as to see that the calls are being answered promptly and politely. The supervisor is provided with a head receiver, and whenever necessary she can plug into the duplicate receiver jack at any operator's position and give temporary assistance.

67. Next below the supervisors are the **monitors,** or special operators, who help the operators to complete all special or unusual connections, and to whom operators refer all requests of subscribers for information as well as all cases of trouble. She records all cases of trouble referred to her, and the record is periodically submitted to the wire chief for action. She tests out all *don't answer* complaints by trying to get a response, and all cases of failure are also referred to the wire chief.

68. Each **operator** has a head-band receiver and usually also a breastplate transmitter. When an operator is about to go on duty she inserts her receiver plug into the duplicate jack of the position she is to occupy and becomes familiar with the active calls before the other operator leaves. The operators are usually arranged in three groups, or forces, which serve for day, evening, and night duty, respectively. Night managers report to the day manager, and under each night manager is a night chief operator, etc.

COMMERCIAL DEPARTMENT

69. The commercial department fixes schedules of rates, secures new business, attends to making contracts, renders bills, makes collections, obtains from the plant department estimates of the cost of special services required by a subscriber so as to submit prices for the service, etc. For example, when a private-branch-exchange system is wanted, the commercial department obtains from the plant department a detailed estimate of the cost of installation to serve as a guide in fixing rentals. In such a case a representative of the plant department must confer with the prospective subscriber to learn his exact requirements, and a representative of the commercial department is usually present at the conference. Substations and extension stations necessitating the installation of additional cable may also be the subject of similar conferences.

ENGINEERING DEPARTMENT

70. The work of keeping in touch with the requirements of the plant, devising improvements in the service or the equipment, planning for increased growth of plant, etc. may be carried on in a separate department under a **plant engineer,** or a bureau under such an engineer may form a part of the plant department.

71. When the building of a new plant is anticipated, detailed preliminary surveys are made by the plant engineers, and drawings prepared showing the results of their survey. With the aid of this data an estimate is prepared covering the cost of the proposed construction. When this estimate has been approved by the plant engineer in charge and by the plant superintendent, it is submitted to the general manager or to an executive committee, and the necessary funds appropriated for carrying on the work. Blueprints of the original drawings are then made for the use of the various gangs in the construction department.

72. Plant engineers usually have general supervision over the maintenance of the outside plant, in that they are kept informed concerning proposed repairs or replacements that involve an appreciable expenditure. This practice is essential because the plans of the plant engineer for renovating and extending the plant often cover a period of two or three years in advance of actual construction, and he may be planning to replace or abandon lines on which such repairs seem necessary.

INDEX

NOTE.—In this Volume, each Section is complete in itself and has a number. This number is printed at the top of every page of the Section in the headline opposite the page number, and to distinguish the Section number from the page number, the Section number is preceded by a section mark (§). In order to find a reference, glance along the inside edges of the headlines until the desired Section number is found, then along the page numbers of that Section until the desired page is found. Thus, to find the reference "Ammeters, §16, p7," turn to the Section marked §16, then to page 7 of that Section.

A

Acoustics, §11, p1
Adjustments, §13, p46
Aerial cable, §15, p25
  cable installation, §15, p21
  wire, §15, p19
Air-gap arrester, §11, p39
Alternating current, §10, p7
Ammeters, §16, p7
Ampere, The, §10, p8
Apartment houses and hotels, Wiring of, §13, p25
Arrester, Air-gap, §11, p39
  Sneak-current, §11, p38
Assignments, Checking conductor, §13, p37

B

Batteries, §12, p52
  Local, §12, p12
  Primary, §10, p5
  Storage, §14, p63
Bells, Polarized, §11, p18
Biased ringer, §12, p8
Block cable, §15, p40
  wiring, §15, p7
Board, New York type No. 1, §12, p45
  Type No. 4 P. B. X., §13, p1
Boards, Multiple, §13, p11
Boxes, Cross-connection, §15, p70
Branch exchange, Magneto private, §12, p44
  exchanges, Auxiliary devices for cord-type, §12, p35
  exchanges, Common-battery private, §12, p44
  exchanges, Private, §12, p30
Bridging magnetos, §11, p20
Bridle wires, §15, p7
Buildings, Wiring large, §13, p24

C

Cable, Aerial, §15, p25
  Block, §15, p40
  Drawing in, §15, p67
  Placing, §15, p35
  sewing, §14, p55
  splices, §15, p50
  terminals, §15, p21
  -testing sets, §16, p9
  Underground, §15, p67
Cables, Conduit for telephone, §15, p46
  Dimensions of sleeves for, §15, p37
  Forming factory, §14, p42
  Forming hand-made, §14, p47
  Hand-made, §14, p41
  House, §15, p45
  Paper-insulated, §15, p49
  Placing lateral, §15, p70
  Splicing underground, §15, p71
  Switchboard, §14, p40
  Testing underground, §15, p71
Call circuits, §14, p24
  from central office to extension station, §13, p5
Calls from extension stations, §13, p9
Capacity, Electrostatic, §10, p13
  Specific inductive, §10, p14
Cell, Voltaic, §10, p5
Central office, §11, p27
  -office equipment, §11, p27
  -office equipment, Auxiliary, §14, p3
  office, General features of a telephone, §14, p1
  office to extension station, Call from, §13, p5
  -office trouble, Order of clearing, §16, p23
  -office wiring, §14, p39

Central office, Wiring in a small, §14, p51
  offices, Classification of, §14, p1
  offices, Definition of, §14, p1
Charges, Electric, §10, p12
Charging current for storage batteries, Sources of, §14, p68
  storage batteries, §14, p64
  trunks, §13, p10
Checking conductor assignments, §13, p37
Chemical effect of electric current, §11, p39
Chief operator, §16, p30
Circuit, Closed, §10, p11
  Grounded, §10, p11
  Inductive, §10, p40
  Magnetic, §10, p20
  Metallic, §10, p11
  Non-inductive, §10, p39
  Open, §10, p11
  Short, §10, p12
Circuits, Cord, §13, p5
  Electric, §10, p11
  Trunk, §13, p4; §14, p25
Clearing central-office trouble, Order of, §16, p23
Climbers, §15, p18
Closed circuit, §10, p11
Code, Color, §14, p40
Coil, Magnetizing, §10, p28
  Primary, §10, p34
  Secondary, §10, p34
Coils, Impedance, §10, p38
  Induction, §10, p34; §12, p6
  Retardation, §10, p38
Color code, §14, p40
Commercial department, §16, p31
Common-battery board, Multiple, §14, p18
  -battery boards, Non-multiple, §14, p15
  -battery exchanges, §11, p31
  -battery instruments, §12, p16
  -battery party lines, §12, p21
  -battery power plants, §14, p63
  -battery private branch exchanges, §12, p44
  -battery switchboard, §14, p14
Company organization, §16, p26
Compass needle, §10, p17
Condensers, §10, p13; §12, p12
Conductor assignments, Checking, §13, p37
Conductors, §10, p10
  in parallel, §10, p12
  in series, §10, p11
  Installation of, §13, p19
Conduit for telephone cables, §15, p46
  subways, §15, p61
Connections between central office and an extension station, §12, p51
  between two extension stations, §12, p50
  Night-service, §13, p8
Connections, Transmitter, §11, p12
Construction department, §16, p26
  Subway, §15, p60
Contact, Ring, §12, p36
  Sleeve, §12, p36
  Tip, §12, p36
Copper wire, §13, p18
Cord circuit of a No. 1 relay board, §14, p20
  circuits, §13, p5
  -type branch exchanges, Auxiliary devices for, §12, p35
Cordless switchboard, §12, p30
Cords, §12, p37
Cribbing, §15, p27
Cross-connection boxes, §15, p70
Current, Alternating, §10, p7
  Chemical effect of electric, §11, p39
  Continuous, §10, p7
  Direct, §10, p7
  Electric, §10, p1
  Fluctuating, §10, p7
  Heating effect of electric, §11, p36
  Magnetic effect of electric, §10, p22
  Pulsating, §10, p7
  Voice, §11, p7
Currents, Foreign, §16, p1
Cut-off jack, §12, p36

D

Department, Commercial, §16, p31
  Construction, §16, p26
  Engineering, §16, p32
  Equipment, §16, p27
  Plant, §16, p26
  Record, §16, p29
  Traffic, §16, p30
Deportment, General, §13, p36
Desk set, Common-battery, §12, p18
  sets, Magneto, §12, p14
Dielectric, §10, p13
Direct current, §10, p7
Distributing frame, Intermediate, §14, p36
Drawing in cable, §15, p67
Drop of potential, §10, p3
  wiring, §15, p3
Drops, §14, p13

E

Electric charges, §10, p12
  circuits, §10, p11
  current, §10, p1
  -lamp signals, §12, p40
  potential, §10, p1
  resistance, §10, p2
  signaling, §11, p15
Electrical hazards, §11, p36
  measuring instruments, §10, p25

Electricity, §10, p1
  Direction of flow of, §10, p2
  Static, §10, p12
Electrodes, §10, p6
Electrolysis, §11, p39
Electrolyte, §10, p6
Electromagnetic induction, §10, p31
  solenoid, §10, p24
Electromagnets, §10, p26
  in telegraphy, §10, p30
Electromotive force of self-induction, §10, p37
  forces, Induced, §10, p31
Electrostatic capacity, §10, p13
Engineering department, §16, p32
Equipment department, §16, p27
  Single-station, §12, p1
Exchange, Magneto private branch, §12, p44
  The telephone, §11, p26
Exchanges, Auxiliary devices for cord-type branch, §12, p35
  Common-battery, §11, p31
  Common-battery private branch, §12, p44
  Magneto, §11, p27
  Private branch, §12, p30
Expansion shields, §15, p9
  station, Call from central office to, §13, p5
  station, Connections between central office and an, §12, p51
  stations, Calls from, §13, p9
  stations, Connections between two, §12, p50
  telephones, §12, p24
  telephones, Typical plans for, §12, p25
Extraneous currents, §16, p1

F

Factory cables, Forming, §14, p42
Faults, Determination of, §16, p16
  Location of, §16, p19
Field, Magnetic, §10, p19
Final test, §13, p49
Flow of electricity, Direction of, §10, p2
Flux, Magnetic, §10, p20
Foreign currents, §16, p1
Forming factory cables, §14, p42
  hand-made cables, §14, p47
Four-party line, §12, p23
Frame, Intermediate distributing, §14, p36
  Main, §14, p32
  protection, Main-, §14, p35
Frequency, §10, p7
Fuse, §11, p38

G

Galvanometers, §16, p6
Gauges, Wire, §13, p15
Generators, Magneto, §11, p15; §12, p9
Granular-carbon transmitter, §11, p11
Grounded circuit, §10, p11
Guy stub, §15, p25

H

Hand-made cables, §14, p41
  -made cables, Forming, §14, p47
Hazards, Electrical, §11, p36
Heating effect of electric current, §11, p36
Hook switch, §11, p22; §12, p11
Horseshoe magnet, §10, p19
Hotels and apartment houses, Wiring of, §13, p25
House cables, §15, p45
Howler, §16, p13

I

Impedance, §10, p37
  coils, §10, p38
Induced electromotive forces, §10, p31
Induction coils, §10, p34; §12, p6
  Electromagnetic, §10, p31
  Magnetic, §10, p21
  Mutual, §10, p33
  Self-, §10, p36
Inductive capacity, Specific, §10, p14
  circuit, §10, p40
  disturbances in telephone circuit, §11, p24
Inspection and tests, General, §13, p39
  Necessity for, §16, p1
Inspections, Routine, §13, p40
Installation, Aerial cable, §15, p21
  of conductors, §13, p19
  of telephones, §13, p33
Installers, Instructions to, §13, p35
Installing protectors, Instructions for, §13, p14
  telephone apparatus, §13, p15
Instructions to installers, §13, p35
Instruments, Common-battery, §12, p16
  Electrical measuring, §10, p25
  Magneto, §12, p13
  Testing and measuring, §16, p3
Insulator, Strain, §15, p56
Insulators, §10, p10
Interior wiring, §13, p15
Intermediate distributing frame, §14, p36

J

Jack, §11, p28
  Cut-off, §12, p36
Jacks, §12, p35; §14, p13
  Multiple, §14, p2
Joint, McIntyre, §13, p23
  use of poles, §15, p54

K

Key, Listening, §11, p29
  Ringing, §11, p29
Keyless trunk, §14, p30

L

Law, Ohm's, §10, p8
Line circuit of a No. 1 relay board, §14, p19
  Four-party, §12, p23
  signals, §12, p38
  Two-party, §12, p22
Lineman's test set, §16, p3
  test set, Use of, §16, p24
Lines of magnetic force, §10, p19
  Pole, §15, p9
Listening key, §11, p29
Local batteries, §12, p12
Location of faults, §16, p19
Loose-contact transmitters, §11, p11
Loudness, §11, p2
Lover's telephone, §11, p6

M

Magnet, Horseshoe, §10, p19
  Permanent, §10, p16
Magnetic circuit, §10, p20
  effect of electric current, §10, p22
  field, §10, p19
  flux, §10, p20
  force, Lines of, §10, p19
  induction, §10, p21
  reluctance, §10, p27
Magnetism, §10, p16
  Residual, §10, p21
Magnetizing coil, §10, p28
Magneto exchanges, §11, p27
  generators, §11, p15; §12, p9
  instruments, §12, p13
  -line circuits, Operation of, §14, p8
  party lines, §12, p20
  power plant, §14, p61
  private branch exchange, §12, p44
  switchboards, §14, p4
  transmitters, §11, p9
Magnetos, Bridging, §11, p20
  Series, §11, p20
Magnets, §10, p16
Main frame, §14, p32
  -frame protection, §14, p35
Maintenance of subscribers' equipment, §13, p39
  Plant, §16, p1
McIntyre joint, §13, p23
Mechanical-drop signals, §12, p38
Messenger strand, §15, p25
Metallic circuit, §10, p11
Microfarad, §10, p14
Micrometer, §13, p15
Microphone, §11, p11
Milonite nails, §13, p20
Monitors, §16, p31
Multiple boards, §13, p11
  common-battery board, §14, p18
  jacks, §14, p2
Multi-position boards, §14, p1
Murray loop tests, §16, p19
Mutual induction, §10, p33

N

Nails, Milonite, §13, p20
Neutral zone, §10, p17
New York type No. 1 board, §12, p45
Night-alarm attachment, §14, p14
  alarm signals, §12, p39
  -service connections, §13, p8
Non-inductive circuit, §10, p39
  -multiple common-battery boards, §14, p15
Number 1 relay board, Cord circuit of a, §14, p20
  1 relay board, Line circuit of a, §14, p19

O

Office buildings, Wiring of, §13, p28
Ohm, The, §10, p8
Ohm's law, §10, p8
Open circuit, §10, p11
Operation of magneto-line circuits, §14, p8
  Trunk, §14, p27
Operator, §16, p31
  Chief, §16, p30
Operator's talking circuit, §14, p24
Order wires, §14, p24
Organization, Company, §16, p26

P

Paper-insulated cables, §15, p49
Parallel, Conductors in, §10, p12
Party line, §11, p27
  -line telephones, §12, p20
  lines, Common-battery, §12, p21
  lines, Magneto, §12, p20
Permanent magnet, §10, p16
Pilot signals, §13, p10
Pitch, §11, p2
Placing cable, §15, p35
  lateral cables, §15, p70
  poles, §15, p13
Plans for extension telephones, Typical, §12, p25
Plant department, §16, p26
  Magneto power, §14, p61
  maintenance, §16, p1
  Power, §14, p61
  records, §13, p35
  Surface, §15, p1
  Underground, §15, p60
Plants, Common-battery power, §14, p63
Plug socket, §11, p28

Plugs, §12, p35
Polarized bells, §11, p18
Poled, §13, p42
Pole hardware, §15, p12
  lines, §15, p9
Poles, Action between, §10, p18
  Joint use of, §15, p54
  Magnetic, §10, p17
  Placing, §15, p13
  Telephone, §15, p9
Potential, Drop of, §10, p3
  Electric, §10, p1
Pothead, §15, p53
Power plant, §14, p61
  plant, Magneto, §14, p61
  plants, Common-battery, §14, p63
  switchboard, §14, p72
Primary batteries, §10, p5
  coil, §10, p34
Private branch exchanges, §12, p30
Protected terminals, §15, p21
Protection, Main-frame, §14, p35
  Means of, §13, p12
  Subscribers' station, §13, p11
  Telephone, §11, p36
Protectors, Instructions for installing, §13, p14

R

Racks, Relay, §14, p39
Reactance, §10, p37
Receiver, Telephone, §11, p8
Receivers, §12, p5
Record department, §16, p29
Records, Plant, §13, p35
Relay racks, §14, p39
Relays, §12, p41
Reluctance, §10, p27
Repeating coils, §14, p11
Reproduction of sound, §11, p5
Residual magnetism, §10, p21
Resistance, Electric, §10, p2
Resuscitation after electric shock, §15, p58
Retardation coils, §10, p38
Reversed pair, §16, p2
Ring contact, §12, p36
Ringer, Biased, §12, p8
Ringers, §12, p7
Ringing key, §11, p29
  machines, §14, p70
Routine inspections, §13, p40

S

Secondary coil, §10, p34
Self-induction, §10, p36
  -induction, Electromotive force of, §10, p37
Series, Conductors in, §10, p11
Series magnetos, §11, p20
Sewing, Cable, §14, p55
Shock, Resuscitation after electric, §15, p58
Short circuit, §10, p12
Signal, Visual-target, §11, p32
Signaling connections, §11, p19
  Electric, §11, p15
  the operator, §11, p31
  the subscriber, §11, p34
Signals, Electric-lamp, §12, p40
  Line, §12, p38
  Mechanical-drop, §12, p38
  Night-alarm, §12, p39
  Pilot, §13, p10
  Visual-target, §12, p39
Single-position boards, §14, p1
  -station equipment, §12, p1
Sleeve contact, §12, p36
Sleeves for cables, Dimensions of, §15, p37
Sneak-current arrester, §11, p38
Soldering, §14, p50
Solenoid, Electromagnetic, §10, p24
Sound, Cause and nature of, §11, p1
  Loudness of, §11, p2
  Pitch of, §11, p2
  Reproduction of, §11, p5
  Timbre of, §11, p2
Specific inductive capacity, §10, p14
Splice, Tap, §15, p51
  Y, §15, p53
Splices, Cable, §15, p50
  Straight, §15, p50
Splicing inside wires, §13, p22
  underground cables, §15, p71
Split pairs, §16, p2
Static electricity, §10, p12
Station troubles, Subscribers', §13, p45
Storage batteries, §14, p63
  batteries, Care of, §14, p64
  batteries, Charging, §14, p64
  batteries, Sources of charging current for §14, p68
Straight splices, §15, p50
Strain insulator, §15, p56
Subscribers' equipment, Maintenance of, §13, p39
  instruments, Types of, §12, p13
  lines, §11, p27
  multi-station systems, §12, p24
  station, §11, p26
  station equipment, §11, p27
  station protection, §13, p11
  station troubles, §13, p45
Subway construction, §15, p60
Subways, Conduit, §15, p61
  Dimensions of manholes for telephone, §15, p65

Superintendent of traffic, §16, p30
Supervisors, §16, p31
Surface plant, §15, p1
Switchboard, Arrangement of apparatus in a large, §14, p57
  cables, §14, p40
  Cordless, §12, p30
  Power, §14, p72
  tests, §16, p22
  wire, §14, p39
Switchboards, Common-battery, §14, p14
  Magneto, §14, p4
Switch, Hook, §11, p22; §12, p11
Systems, Subscribers' multi-station, §12, p24

T

Talking circuit, Operator's, §14, p24
Tap splice, §15, p51
Target signal, Visual, §11, p32
Telegraphy, Electromagnets in, §10, p30
Telephone apparatus, Installing, §13, p15
  boards, Multi-position, §14, p1
  boards, Single-position, §14, p1
  central-office, General features of a, §14, p1
  circuit, Inductive disturbances in, §11, p24
  exchange, The, §11, p26
  instruments, Component parts of, §12, p2
  Lover's, §11, p6
  poles, §15, p9
  protection, §11, p36
  receiver, §11, p8
  switchboard, Arrangement of apparatus in a large, §14, p57
  transmitter connections, §11, p12
  transmitters, §11, p9
  transmitters, Variable-resistance, §11, p10
Telephones, Extension, §12, p24
  Installation of, §13, p33
  Party-line, §12, p20
Telephony, Terms used in, §13, p41
Terminal apparatus, §14, p31
Terminals, Cable, §15, p21
  Protected, §15, p21
  Unprotected, §15, p23
Terms used in telephony, §13, p41
Test, Ballistic, §16, p19
  Final, §13, p49
  for a ground, §16, p18
  for a short circuit, §16, p17
  for continuity, §16, p17
  set, Lineman's, §16, p3
  set, Use of lineman's, §16, p24
  Varley loop, §16, p21
Testing and measuring instruments, §16, p3
  and measuring sets, Cable-, §16, p9
  equipment, Wire chief's, §16, p10
  Methods of, §16, p16
Testing underground cables, §15, p71
Tests and inspection, General, §13, p39
  Common-battery instrument, §13, p45
  Common-battery wiring, §13, p45
  for crosses, §16, p18
  Miscellaneous, §13, p46
  Murray loop, §16, p19
  Necessity for, §16, p1
  Switchboard, §16, p22
  with a telephone receiver, §13, p43
Timbre, §11, p2
Tip contact, §12, p36
Toll lines, §11, p27
Tracings, §14, p10
Traffic department, §16, p30
  manager, Chief, §16, p30
  Superintendent of, §16, p30
Transmitter connections, §11, p12
  Granular-carbon, §11, p11
Transmitters, §12, p2
  Loose-contact, §11, p11
  Telephone, §11, p9
  Telephone magneto, §11, p9
  Variable-resistance, §11, p10
Transposed pairs, §16, p2
Trouble, Order of clearing central-office, §16, p23
Troubles, Subscriber's station, §13, p45
Trunk circuits, §13, p4; §14, p25
  Keyless §14, p30
  lines, §11, p27
  operation, §14, p27
Trunking, General plan of, §14, p3
Trunks, Charging, §13, p10
Two-party line, §12, p22
Type No. 4 P. B. X. board, §12, p1

U

Underground cable, §15, p67
  plant, §15, p60
Unprotected terminals, §15, p23

V

Variable-resistance transmitters, §11, p10
Varley loop test, §16, p21
Visual-target signal, §11, p32
  -target signals, §12, p39
Voice current, §11, p7
Voltaic cell, §10, p5
Voltmeters, §16, p7
Volt, The, §10, p8

W

Wall set, Common-battery, §12, p16
  sets, Magneto, §12, p13
Wheatstone bridge, The, §16, p4

Wire, Aerial, §15, p19
  chief's testing equipment, §16, p10
  Copper, §13, p18
  gauges, §13, p15
  Switchboard, §14, p39
Wires, Bridle, §15, p7
  Fastening inside, §13, p20
  General method of running, §13, p19
  Splicing inside, §13, p22
Wiring, Block, §15, p7
Wiring, Central-office, §14, p39
  Drop, §15, p3
  in a small central-office, §14, p51
  Interior, §13, p15
  large buildings, §13, p24
  of hotels and apartment houses, §13, p25
  of office buildings, §13, p28

Y

Y splice, §15, p53

168 08/00
7002 69
ICI
INFORMATION
CONSERVATION, INC.

m

89071936447

B89071936447A

Thi

89071909600

B89071909600A

DEMCO

K.F. WENDT LIBRARY
UW COLLEGE OF E
215 N. RANDALL AV
MADISON WI 53

89071909600

b89071909600a